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TRANSMISSION OF POWER BY COMPRESSED AIR.

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II.

CHAPTER IV.

THE THERMODYNAMIC EQUATIONS APPLIED TO PERMANENT GASES.

I.

DETERMINATION OF THE SPECIFIC HEAT AT CONSTANT VOLUME.

Forming, from eq. (3), the partial differentials:

$$\left(\frac{dt}{dp}\right)=\frac{V}{R},\left(\frac{dt}{dv}\right)=\frac{p}{R},\frac{d^2t}{dp.dv}=\frac{1}{R},$$

and substituting in eqs. (20) and (21), we have:

$$(c-c')=\frac{1}{J}R, \qquad (22)$$

and $$\Phi(t)=\frac{pV}{R}=(a+t) \qquad (23)$$

(22) gives, $c'=c-\frac{1}{J}R=.238-\frac{96.0376}{1389.6}=.169$

which is the specific heat at constant volume for atmospheric air.

II.

INTERNAL HEAT.

Placing eqs. (12) and (15) equal to each other and substituting the value of c from (22), we have:

$$\left(\frac{du}{dp}\right)dp+\left(\frac{du}{dv}\right)dv=c'(vap+pdv)\frac{1}{R}=du,$$

according to eq. (11).

Integrating, and substituting for R its value $\frac{pv}{\tau}$ we have,

$$u=c'\tau-u_0$$

or $$u-u_0=c'\tau \qquad (24)$$

which shows that the internal heat for every degree of temperature is increased by a quantity c' (.169), and the increase of the internal heat of a gas passing from 0°C. to t°C. is always the same, whatever variations its pressure may have undergone in this passage, the volume having been kept constant.

III.

QUALITY OF HEAT SUPPLIED.

The partial differentials formed from eq. (3) placed in (15) gives:

$$dQ=\frac{c'vdp+cpdv}{R} \qquad (25)$$

which is integrable only when we have a given relation between p and v.

1. At constant volume; make $dv=o$, v being constant. Then

$$Q=\int_{p_0}^{p}\frac{c'vdp}{R}=\frac{c'v(p-p_0)}{R}=c'(\tau-\tau_0) \qquad (25a)$$

which defines the specific heat at constant volume.

2. At constant pressure; here $dp=o$, and eq. (25) gives:

$$Q=\frac{cp(v-v_0)}{R}=c(\tau-\tau_0) \qquad (25b)$$

IV.

EXPANSION AT A CONSTANT TEMPERATURE.

To find the work done by a gas expanding *isothermally*, (that is, the absolute temperature is maintained at a constant value), we must satisfy Boyle's law and write:

$$pv=p_0v_0=\text{constant};$$

hence $pdv+vdp=o$; or, $vdp=-pdv$. Substituting this in (25),

$$dQ=\frac{(c-c')pdv}{R}=\frac{1}{J}pdv;$$

Introducing p from eq. (3),

$$da=\frac{1}{J}R(a+t)\frac{dv}{v},$$

and,

$$Q=\frac{1}{J}R(a+t)\int_{v_0}^{v}\frac{dv}{v}=\frac{1}{J}R(a+t)\log.\frac{v}{v_0}.$$

$$=\frac{1}{J}p_0v_0\log.\frac{v}{v_0} \qquad (26.)$$

Let W = the work done; then

$$W=p_0v_0\log.\frac{v}{v_0}. \qquad (26a.)$$

the ordinary form for permanent gases.

V.

EXPANSION IN A PERFECTLY NON-CONDUCTING CYLINDER.

If a gas expand *adiabatically*, (*i.e.*, without any passage of heat either into the gas from without or out of the gas into other substances) $dQ=o$ in eq. (25), and we have,

$$c'vdp+cpdv=o.$$

Writing for $\frac{c}{c'}$ its value r, and integrating, we have

$$\int_{p_0}^{p}\frac{dp}{p}+r\int_{v_0}^{v}\frac{dv}{v}=\log.\frac{p}{p_0}+r\log.\frac{v}{v_0}=o$$

$$=\log.\frac{p}{p_0}+\log.\frac{v^r}{v_0^r}=o$$

or, $\log.\frac{p}{p_0}=\log.\frac{v}{v_0}\times(-r)=\log.\frac{v_0^r}{v^r}$

hence, $pv^r=p_0v_0^r=\text{constant};$ (27)

an equation which expresses the variation of pressure as a function of volume when the expansion or compression is *adiabatic*.

The external work performed during a finite expansion is denoted by

$$W=\int_{v_0}^{v}pdv=\int_{v_0}^{v}p_0v_0^r\frac{dv}{v^r}=p_0v_0^r\int_{v^0}^{v}v^{-r}\,dv \qquad (27a)$$

$$=\frac{p_0v_0^r}{r-1}\left(\frac{1}{v_0^{r-1}}-\frac{1}{v^{r-1}}\right)=\frac{p_0v_0}{r-1}\left\{1-\left(\frac{v_0}{v}\right)^{r-1}\right\}. \qquad (28)$$

Since no heat is received from without, the thermal equivalent of the work must be estimated as *internal* heat. If, now, τ_0 and τ are the initial and final absolute temperatures, the decrease in internal heat will be

$$c'(\tau_0-\tau).$$

Hence we must have,

$$c'(\tau_0-\tau)=\frac{1}{J}\frac{p_0v_0}{r-1}\left\{1-\left(\frac{v_0}{v}\right)^{r-1}\right\} \qquad (29)$$

Eq. (27) gives $\frac{pv^r}{p_0v_0^r}=1$; multiplying both members by $\frac{v_0^{r-1}}{v^{r-1}}$ we have,

$$\frac{pv}{p_0v_0}=\left(\frac{v}{v_0}\right)^{r-1}=\frac{a+t}{a+t_0}=\frac{\tau}{\tau_0}; \qquad (30)$$

also,

$$\frac{v_0^r}{v^r}=\frac{p}{p_0},\text{ and }\frac{v_0}{v}=\left(\frac{p}{p_0}\right)^{\frac{1}{r}}.$$

hence,

$$\left(\frac{v_0}{v}\right)^{r-1}=\left(\frac{p}{p_0}\right)^{\frac{r-1}{r}}=\frac{a+t}{a+t_0}=\frac{\tau}{\tau_0} \qquad (31)$$

Substituting in (28) the values of p_0v_0 from (3) and $\left(\frac{v_0}{v}\right)^{r-1}$ from (31) we obtain:

* The logarithms, it is seen, are taken in the Naperian system.

$$W=\frac{R(a+t_0)}{r-1}\left\{1-\left(\frac{p}{p_0}\right)^{\frac{r-1}{r}}\right\} \qquad (32)$$

a form often used $\frac{r-1}{r}=.2908$.

VI.

Variations in the temperature of a gas during expansion or compression in a perfectly non-conducting cylinder.

Placing the second members of $p_0v_0=R(a+t_0)$, $r=\frac{c}{c'}$, and $J=\frac{c-c'}{R}$ in eq. (29) we get:

$$t_0-t=\tau\left\{1-\left(\frac{v_0}{v}\right)^{r-1}\right\}, \qquad (33)$$

which is thus interpreted:

The decrease in temperature (during an expansion from v_0 to v) is proportional to the initial absolute temperature.

The already established relation,

$$\frac{\tau}{\tau_0}=\left(\frac{v_0}{v}\right)^{r-1}$$

expresses the final temperature as a function of the volumes; and if we know the initial and final pressures, the final temperature is expressed as a function of these pressures as follows:

$$\frac{a+t}{a+t_0}=\frac{\tau}{\tau_0}=\left\{\frac{p}{p_0}\right\}^{\frac{r-1}{r}}$$

CHAPTER V.

Thermodynamic Laws Applied to the Action of Compressed Air.*

I

FUNDAMENTAL FORMULAS.

The four equations formulating the law for the expansion and compression of dry air, are, as we have established them,

$$\frac{pv}{a+t}=Rw=\frac{pv}{\tau}=J(c-c')w \qquad (34a)$$

$$\frac{p}{p_0}=\left\{\frac{v_0}{v}\right\}^r=\left\{\frac{v_0}{v}\right\}^{\frac{c}{c'}} \qquad 34\ b)$$

$$\frac{\tau}{\tau_0}=\left\{\frac{v_0}{v}\right\}^{r-1}=\left\{\frac{v_0}{v}\right\}^{\frac{c}{c'}-1} \qquad (34c)$$

$$\frac{\tau}{\tau_0}=\left\{\frac{p}{p_0}\right\}^{\frac{r-1}{r}}=\left\{\frac{p}{p_0}\right\}^{\frac{\frac{c}{c'}-1}{\frac{c}{c'}}} \qquad (34d)$$

* The subject of this chapter is very ably treated by M. Mallard, in the "Bulletin de la Société de l' industrie minerale," tome xii, page 615, to whom the writer is greatly indebted.

These expressions sum up the relations existing between the *pressure*, *volume* and *absolute temperature* of a weight of air w compressed or expanded in a perfectly non-conducting cylinder.

p_0, τ_0, and v_0 have reference to the *initial* state of the weight of air considered, p, τ and v corresponding to the final state.

The following table is that of MM. Mallard and Pernolet. It gives for convenient values of $\frac{p}{p_0}$ the corresponding values of $\frac{\tau}{\tau_0}$, &c. The tabular differences facilitate interpolation.

(*See Table on following page.*)

II.

WORK SPENT IN COMPRESSING AIR.

The compressing-cylinder being supposed perfectly non-conducting as to heat, our machine may be called a "Reversible Engine;" for by reversing the process of compression under exactly the same conditions, we get back the exact amount of work spent in the compression.

The net work necessary to compress a weight of air w, taken from a reservoir (as the atmosphere) in which the pressure p_0 is kept constant, and to force it into another reservoir in which the pressure is constantly p_1, is made up of the following parts:—

1. The work of compression:
2. Diminished by the work due to the pressure p_0 of the first reservoir (the atmosphere); this work is p_0v_0, v_0 being the volume of weight w under pressure p_0 and at the temperature t_0:
3. Increased by the work necessary to force the compressed air into the receiving reservoir; this is given by the expression p_1v_1, v_1 being the volume of a weight of air w at the pressure p_1 and temperature t_1.

As no heat passes between the air and external bodies, the thermal equivalent of the work, according to the mechanical theory of heat, is the difference between the quantity of internal heat possessed by the air at its entrance into the cylinder, and that possessed by it its exit.

The heat possessed by the air at its entrance into the cylinder is,

$$wc'\tau_0;$$

TABLE I.

$\frac{p}{p_0}$	$\frac{\tau}{\tau_0}$		$\frac{\tau_0}{\tau}$		$1-\frac{\tau_0}{\tau}$	$\frac{v_0}{v}$		$\frac{v}{v_0}$		$\frac{t_a}{t}$	
	Numbers.	Differences.	Numbers.	Differences.	Numbers.	Numbers.	Differences.	Numbers.	Differences.	Numbers.	Differences.
1.2	1.0543	481	.9485	415	.0515	1.1382	1317	.8786	911	.793	78
1.4	1.1024	436	.9070	344	.0930	1.2699	1262	.7875	712	.695	53
1.6	1.1416	439	.8762	293	.1274	1.3961	1218	.7163	575	.642	39
1.8	1.1859	367	.8433	254	.1567	1.5179	1179	.6588	475	.603	32
2	1.2226	343	.8179	223	.1821	1.6358	1145	.6113	400	.571	25
2.2	1.2569	321	.7956	198	.2044	1.7503	1116	.5713	342	.546	22
2.4	1.2890	303	.7758	178	.2242	1.8619	1088	.5371	297	.524	19
2.6	1.3193	187	.7580	161	.2420	1.9707	1065	.5074	260	.505	17
2.8	1.3480	272	.7419	147	.2581	2.0772	1043	.4814	230	.488	15
3	1.3752	260	.7272	124	.2728	2.1815	1023	.4584	205	.473	13
3.2	1.4012	248	.7138	125	.2862	2.2838	1005	.4379	185	.460	12
3.4	1.4260	238	.7013	116	.2987	2.3843	587	.4194	167	.448	10
3.6	1.4498	230	.6897	107	.3103	2.4830	972	.4027	151	.438	10
3.8	1.4728	220	.6790	100	.3210	2.5802	957	.3876	139	.428	9
4	1.4948	213	.6690	94	.3310	2.6759	943	.3737	127	.419	9
4.2	1.5161	206	.6596	89	.3404	2.7702	930	.3610	117	.410	8
4.4	1.5367	200	.6507	81	.3493	2.8632	118	.3493	111	.402	7
4.6	1.5567	193	.6424	79	.3576	2.9550	906	.3384	101	.395	7
4.8	1.5760	188	.6345	75	.3655	3.0456	896	.3283	93	.388	6
5	1.5948	865	.6270	322	.3730	3.1352	4333	.3190	388	.382	27
6	1.6813	769	.5948	260	4052	3.5685	4129	.2802	290	.355	19
7	1.7582	694	.5684	217	.4512	3.9814	3858	.2512	227	.334	19
8	1.8276	636	.5471	183	.4529	4.3772	3817	.2285	184	.317	14
9	1.8712	588	.5288	159	.4712	4.7589	3697	.2101	151	.303	12
10	1.9500	544	.5128	141	.4871	5.1286	3583	.1950	126	.291	10
11	2.0044	512	.4988	124	.5012	5.4869	3484	.1824	111	.281	9
12	2.0556	484	.4864	111	.5136	5 8353	3430	.1713	95	.272	9
13	2.1040	457	.4753	101	.5247	6.1783	334	.1618	83	.263	7
14	2.1497	434	.4652	92	.5348	6.5123	3273	.1535	73	.256	6
15	2.1931		.4560		.5440	6.8396		.1462		.250	

The internal heat at its exit is,

$$wc'\tau_1.$$

Hence the work of compression is,

$$Jwc'\tau_1 - Jwc'\tau_0 = Jwc'(\tau_1 - \tau_0),$$

and the net work is,

$$W_1 = Jc'w(\tau_1 - \tau_0) - p_0v_0 + p_1v_1.$$

Substituting for p_0v_0 and p_1v_1 their values from eq. (34*a*) we have,

$$W_1 = Jwc(\tau_1 - \tau_0) \qquad (35)$$

an equation perfectly general for dry atmospheric air.

III.

WORK OBTAINABLE FROM THE COMPRESSED AIR.

If, by any process, we cause a weight of air w to pass from one reservoir, in which there is a constant pressure p_0, into another reservoir, in which there is a constant pressure p_1, and thereby consume an amount of work W_1, the same weight of air w (supposing the air to remain in the same physical conditions) will restore the amount of consumed work W_1 in passing back from the second reservoir into the first. These are the conditions of a perfect thermodynamic engine.

The work theoretically obtainable from compressed air is therefore, eq. (35),

$$W_1 = Jwc(\tau_1 - \tau_0)$$

an equation which shows how important it is to take into account the initial and final temperature of the air.

IV.

THE THEORY OF COMPRESSION.

1. The work necessary and the volume of the Compressing-Cylinder. Neglecting

all dead spaces and resistances, we can easily calculate, by the aid of our formulas and of table I, the work necessary to compress to a pressure p_1 a weight of air w, taken at a pressure p_0 and a temperature τ_0, as well as the volume to be given to the cylinder of the compressor to compress a given weight of air w per second, the time T being given in seconds.

Our formulas are :

$$W_1 = Jwc(\tau_1 - \tau_0) = Jwc\tau_0\left\{\frac{\tau_1}{\tau_0} - 1\right\}, \quad (35a)$$

when a final temperature τ_1, which is not to be exceeded, is assumed, the value of $\frac{\tau_1}{\tau_0}$ being obtained as a function of $\frac{p_1}{p_0}$ from table 1, or from an adiabatic curve.

$$W_1 = Jwc\left\{\left(\frac{p_1}{p_0}\right)^{\frac{r-1}{r}} - 1\right\}, \quad (35b)$$

when a pressure p_1, to which we wish to attain, is assumed.

$$W_1 = p_0 v_0 \frac{r}{r-1}\left\{\frac{\tau_1}{\tau_0} - 1\right\}, \quad (35c)$$

an equation employed when we wish to find W_1 as a function of the volume v_0 of the air instead of as a function of its weight. This equation is obtained by substituting in eq. (35*a*.) the value of τ_0 from eq. (34*a*.), and r for $\frac{c}{c'}$.

From eq. (34*a*.) we have,

$$Y_1 = Rw\frac{\tau^0}{p_0} \times T, \quad (36)$$

an equation for the volume of the cylinder which compresses per second a weight of air w, when the time, T, required per single stroke of the compressor (or per double stroke when the compressor is single-acting), is given in seconds.

2. The final temperature of the compressed air. This is found by looking in Table I. for the values of $\frac{\tau}{\tau_0}$ opposite the different values of $\frac{p}{p_0}$. Supposing the initial temperature $\tau_0 = 293° = 20°$C., we find for the different values of $\frac{p}{p_0}$ the values of τ_1 in degrees of absolute temperature and degrees C., as follows :

TABLE II.

$\frac{p_1}{p_0}$	τ_1	Final Temperature in Degrees C.
2	358.2	85.2
3	402.9	129.9
4	437.9	164.9
5	467.2	194.2
6	492.6	219.6
7	515.1	242.1
8	535 4	262.4
9	554.1	281.1
10	571.3	298.3
11	587.2	314.2
12	602.2	329.2
13	616.4	343.4
14	629.8	356.8
15	642.5	369.5

V.

THE THEORY OF TRANSMISSION.

1. *Loss of Pressure due to Transmission.*—The loss in pressure which results from carrying compressed air from one point to another point distant from the first, is due,

1.° To the friction between the air and the conveying pipes;

2.° To sudden contractions in the pipes;

3.° To sharp turns and elbows.

From experiments made at the Mont Cenis Tunnel, the loss of pressure from friction in pipes was formulated thus:—

$$\triangle p = .00936\frac{u^2 l}{d}, \quad (37)$$

where u=the velocity of the air per second,

l=length of the pipes,

d=diameter " "

Hence the loss of pressure varies, directly as the length of pipe; directly as the square of the velocity of the air in the pipe; inversely as the diameter of the pipe.

If w be the weight of air required by the working-cylinder per second, $3.1416\frac{d^2}{4}u$ being the volume of air passing through the pipe per second, and p_1 and τ_1 being the pressure and absolute temperature respectively of the air in the reservoir, we have, from eq. (34*a*)

$$\frac{3.1416\frac{d^2}{4}up}{\tau_1}=Jw(c-c');$$

Solving with respect to u and substituting in (37), we have,

$$\triangle p=13.88\frac{w^2\tau_1^2 l}{p_1^2 d^5}$$

when Joule's equivalent is taken in French units; when taken in British units (772 foot-pounds per British thermal unit), we have,

$$\triangle p=43.055\frac{\tau_1^2 w^2}{d^5 p^2} l \qquad (38)$$

which expresses the loss of pressure due to friction in the pipes as a function of the weight of air supplied per second, of the temperature and pressure of the air in the reservoir, and of the length and diameter of the pipe.

2. *Difference of Level.*—The difference of level which exists between the reservoir and the compressor and the compressed-air engine (as when the latter is at the bottom of a mine) compensates in part at least for the loss of pressure due to the friction in the supply-pipes. The gain in pressure due to this difference of level is readily calculated by means of the ordinary barometric formulae. (See Wood's Elementary Mechanics, p. 327).

VI.

THE THEORY OF COMPLETE-EXPANSIVE WORKING.

1. *Notation.*—Let θ_0=the absolute temperature of the compressed air when it enters the working cylinder;

θ_1=the absolute temperature of the air after expansion;

ψ_0=the pressure of the compressed air on entering the working-cylinder;

ψ_1=the pressure at the end of expansion.

2. *Work theoretically obtainable.*—This is given in Chap. IV, Section III, and is :

$$W_2=Jwc(\theta_0-\theta_1)=Jwc\theta_0\left\{1-\frac{\theta_1}{\theta_0}\right\}$$

$$=Jwc\theta_0\left\{1-\left(\frac{\psi_1}{\psi_0}\right)^{\frac{r-1}{r}}\right\}, \qquad (39)$$

$\frac{\theta_1}{\theta_0}$ being obtained from the formula for the

3. *Final Temperature.*—This is given by eq. (34*d*) and is :

$$\frac{\theta_1}{\theta_0}=\left\{\frac{\psi_1}{\psi_0}\right\}^{\frac{r-1}{r}}$$

it can be calculated directly by the use of Table I when we know $\frac{\psi_1}{\psi_0}$, the ratio of the final to the initial temperature.

4. *Volume of the Working-Cylinder.*—The volume of the working-cylinder, being the same as the final volume of the air after expansion is, from eq. (34*a*),

$$V_2=Jw\frac{\theta_1}{\psi_1}(c-c')\,T \qquad (40.)$$

where w=the weight of air furnished per second and T=the time in seconds of one stroke.

5. *Weight of Air required per Second.* This is determined by the work which is to be done by the compressed-air engine per second. Letting n be a certain coefficient embracing resistances of all kinds, we have, Chap. IV, Section III.

$$w=\frac{W_2}{k\,Jc(\theta_0-\theta_1)} \qquad (41)$$

Substituting this value of w in eq. (36) we have,

$$V_1=\frac{R}{Jc}\times\frac{W_2T}{k\,(\theta_0-\theta_1)}\times\frac{\tau_0}{p_0}=\frac{r-1}{r}\times\frac{W_2T}{k\,(\theta_0-\theta_1)}\times\frac{\tau_0}{p_0}, \qquad (42)$$

the volume of the compressor in order to supply the given amount of air.

6. *Cold resulting from Expansion.*—While in the compressor there is a great development of heat from the compression of air, in the working-cylinder there is a great fall of temperature due to its expansion. The final temperature θ_1 is calculated from the formula of Chap. IV, Sec. VI, 3.

The valves of $\frac{\theta_1}{\theta_0}$, corresponding to $\frac{\psi_1}{\psi_0}$, and the reciprocals, are found from Table I. The following table is from M. Mallard. The initial absolute temperature is assumed θ_0=293°, that is, 20° C.

This table shows what very low temperatures are reached when we work full expansion with air at a high pressure. Ice is formed from the water-vapor present in the air, and seriously interferes with the action of the working engine.

TABLE III.

$\frac{\psi_1}{\psi_0}$	Final Temperature.	
	Absolute θ_1.	Degrees C.
2	239.6	— 33.4
3	213.0	— 60.0
4	196.0	— 77.0
5	183.7	— 89.3
6	174.2	— 98.8
7	166.6	—106.4
8	160.3	—112.7
9	154.9	—118.1
10	150.1	—122.9
11	146.1	—126.9
12	142.5	—130.5
13	139.2	—133.8
14	136.3	—136.7
15	133.6	—139.4

VII.

THE THEORY OF FULL PRESSURE WORKING.

1. *Work obtainable.*—This is, in the present case, expressed by the equation,

$$W_2 = V_2(\psi_0 - \psi_1). \qquad (43)$$

Placing in this equation the value of V_2 from eq. (40) we have,

$$W_2 = Jw(c-c')\theta_0\left\{1-\frac{\psi_1}{\psi_0}\right\}. \qquad (44)$$

The general expression for the work restored has been given by eq. (39), where θ_1 is the temperature of the air after it has been exhausted and has assumed the pressure of the atmosphere ψ_1.

2. *Final Temperature.*—Placing eqs. (44) and (39) equal to each other,

$$\frac{c-c'}{c}\left(1-\frac{\psi_1}{\psi_0}\right)=\left(1-\frac{\theta_1}{\theta_0}\right)$$

or, $$\frac{\theta_1}{\theta_0}=\frac{1}{r}+\frac{r-1}{r}\frac{\psi_1}{\psi_0}=.7102+.29\frac{\psi_1}{\psi_0} \qquad (45)$$

3. *Weight of Air necessary per Second.*—This is given by eq. (41).

4. *Volume of Cylinder.*—Substituting w, eq. (41), in eq. (34a), we have,

$$V_1=\frac{c-c'}{c}\times\frac{W_2 T}{\psi_0\left\{1-\frac{\theta_1}{\theta_0}\right\}k} \qquad (46.)$$

VIII.

THEORY OF INCOMPLETE EXPANSIVE WORKING.

1. *Work attainable.*—This is given by eq. (39).

2. *Final Temperature.*—We have, eq. (34a),

$$\frac{\theta'_1}{\theta^0}=\left\{\frac{\psi'_1}{\psi_0}\right\}^{\frac{r-1}{r}},$$

from which we get θ'_1 (the température at the end of the stroke). θ_1 is then found from the equation,

$$\frac{\theta_1}{\theta'_1}=\frac{1}{r}+\frac{r-1}{r}+\frac{\psi_1}{\psi_0}.$$

3. *The weight of air used.*—This is given by eq. (41.)

4. *Volume of the Cylinder.*—Eq. (34a), written to satisfy our conditions, becomes:

$$V_1=J(c-c')wT\frac{\theta'}{\psi'^{\frac{1}{r}}_1},$$

or, substituting the value of w from eq. (41),

$$V_1=\frac{r-1}{r}\frac{W_2 T}{\psi'_1\frac{\theta_0}{\theta'_1}\left\{1-\frac{\theta_1}{\theta_0}\right\}}. \qquad (47)$$

IX.

GRAPHICAL REPRESENTATION FOR THE ACTION OF COMPRESSED AIR.

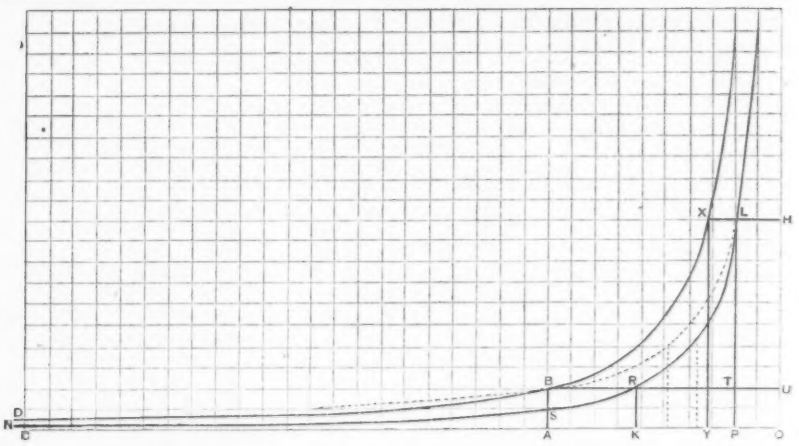
Let abscissas, in diagram on next page, be volumes and ordinates, pressures; taking O for the origin. Through B ($p_0 v_0$) construct an adiabatic curve from its equation, (eq. 27).

"The *intrinsic energy* of a fluid is the energy which it is capable of exerting against a piston in changing from a given state as to temperature and volume, to a total privation of heat and indefinite expansion." The intrinsic of 1 lb. of air at p_0 and v_0, will be represented by the area included between the axis of abscissas, the ordinate AB=p_0 (at a distance from the origin OA=v_0), and the portion of the adiabatic curve extending indefinitely from B until it becomes tangent to the axis of abscissas when $x=\infty$. The algebraic expression for this area (found by integrating eq. (27 a) between the limits ∞ and v_0 is,

$$I=\frac{p_0 v_0}{r-1}. \qquad (47A)$$

p_0=mean pressure of atmosphere in lbs. per square foot=2116.3;

v_0=volume in cubic feet of 1 lb. of air at pressure p_0 and temperature r_0 =12.387;



v_0=493.°2 corresponding to 32° F; r=1.408; hence

$$I=\frac{p_0 v_0}{r-1}=64250 \text{ foot-pounds;}$$

that is, one pound of air, at mean barometer pressure and 32°F, possesses an intrinsic energy of 64250 foot-pounds; and *it is upon this store of energy that we draw, when, after abstracting in the form of heat all the work we had expended in compressing the air, we yet cause it to perform work by expansion.*

Through B construct an isothermal curve from its equation (eq. 1). At a point (as L) chosen arbitrarily upon this curve to correspond to a desired pressure we can construct another adiabatic curve LRN. Then will the relations exist, expressed in the following, as given by Prof. Frazier :.

Area ABDC prolonged indefinitely= intrinsic energy possessed by the air before compression=I.

Area ABLPA=the work performed in compressing the air.

Area DBLRN prolonged indefinitely= ABLPA=energy in the form of heat abstracted by the cooling water; consequently, BSND prolonged indefinitely=ASLPA.

Area CKRN prolonged indefinitely= intrinsic energy of the air after expansion.

Area KRLPK=work performed by the air in its expansion.

Area ABRKA=work performed by the air after it leaves the working-cylinder.

Area DBRSN prolonged indefinitely= ABRLPA=the heat absorbed by the air after leaving the working - cylinder. For isothermal compression, we have,

Area ABLHOA=total work performed in the compressing-cylinder.

Area ABLPA=work performed in the compression of the air.

Area PLHOP=work performed in the expulsion of the air from the compressor.

Area ABUOA=work performed by the atmosphere.

Area UBLHU=ABLPA=the work performed by the motor.

Area UTLHU=useful work performed by the air (full pressure).

Area UBLHU − UTLHU = TLBT= amount of work lost.

For adiabatic compression we have :

Area ABXYA=work performed in the compression of the air.

Area YXHOY=work performed in the expulsion of the air from the compressor.

Area ABUOA=work performed by the atmosphere.

Area BXHUB=work performed by the motor.

Area TLHUT=useful work performed by the air (full pressure).

Area BXLTB=BXHUB−TLHUT= amount of work lost.

When the air is allowed to expand fully (to its original pressure p_0),

Area RTLR=useful work of expansion.

Area UHLRU=total useful work (= UTLHU+RTLR).

Area BXLRB= BXHUB− UHLRU =amount of work lost where air is cooled after leaving the compressor.

Area BLRB = UBLHU−UHLRU= amount of work lost where air is cooled completely in compressor.

The area BLRB represents, then, the excess of work performed on the air above that performed by it, or the amount of work permanently transformed into heat. It is, therefore, not possible, even by preventing any rise of temperature during compression and allowing the air to expand to its full extent, to obtain from the compressed air as much work as was expended in the compression. We can obtain from compressed air all the work expended upon it, only by causing it to reproduce exactly during its expansion the changes of condition it underwent during compression. This may theoretically be accomplished in three ways.

1. By allowing the compressed air to become heated during compression, and preventing all transmission of heat until it leaves the working cylinder. It will be compressed and expand in this case, following the curve BX.

2. By cooling the air during compression and heating it during its expansion, in such a manner that its temperature, shall remain constant during both operations. The air will be compressed and expand in this case, following the curve BL. The heat abstracted during compression will equal that supplied during expansion.

3. By cooling the air *before* its compression to such a degree that after it is compressed it will have the temperature of the media surrounding the working cylinder. The air will be compressed and expand in this case, following the curve RL.

CHAPTER VI.

Efficiency Theoretically Attainable.

I.

Efficiency of the Air-Compressor and Compressed-Air Engine, as a System.

$$\frac{\text{Work performed on the air}}{\text{Work performed by the air}} = \text{the efficiency} = \mathrm{E};$$

hence,

$$\mathrm{E}=\frac{\mathrm{W}_2}{\mathrm{W}_1}=\frac{\mathrm{J}c(\theta_0-\theta_1)w}{\mathrm{J}c(\tau_1-\tau_0)w}=\frac{\theta_0\left\{\frac{\theta_0}{\theta_1}-1\right\}}{\tau_1\left\{\frac{\tau_1}{\tau_0}-1\right\}}$$

$$=\frac{\theta_1}{\tau_0}\times\frac{\left\{\frac{\psi_0}{\psi_1}\right\}^{\frac{r-1}{r}}-1}{\left\{\frac{p_1}{p_0}\right\}^{\frac{r-1}{r}}-1} \qquad (48.)$$

In practice, $\frac{\psi_0}{\psi_1}$ and $\frac{p_0}{p_1}$ differ very little in value, their difference being due to the loss of pressure from the friction between the air and the supply-pipe, a loss which is very small if the pipes are of sufficient diameter.

Hence we may write,

$$\mathrm{E}=\frac{\theta_1}{\tau_0}, \qquad (48a)$$

that is to say, when compressed air is made to expand completely, and when the ratio of its pressure to the pressure of the surrounding atmosphere is the same when the air leaves the compressor as when it enters the cylinder of the compressed-air engine, the efficiency of the system is the ratio of the temperature of the compressed air when it leaves the compressed-air-engine cylinder to the temperature of the air at its entrance into the compressor.

This law is independent of any heat lost by the air in passing from one cylinder to the other.

Since we have just admitted that,

$$\frac{\psi_1}{\psi_0}=\frac{p_0}{p_1}$$

we have,

$$\frac{\theta_1}{\theta_0}=\left\{\frac{\psi_1}{\psi_0}\right\}^{\frac{r-1}{r}}=\left\{\frac{p_0}{p_1}\right\}^{\frac{r-1}{r}}=\frac{\tau_0}{\tau_1};$$

hence,

$$E=\frac{W_2}{W_1}=\frac{\theta_1}{\tau_0}=\frac{\theta_0}{\tau_1}, \qquad (48b)$$

showing that the loss of work is proportional to the loss of heat undergone by the compressed air in its passage from the compressor to the working-cylinder.

The efficiency will be a maximum when $\tau_1=\theta_0$; that is, when the loss of heat is nothing. Of course, this condition cannot be realized. Generally the compressed air reaches the working cylinder with a temperature equal to that of the surrounding atmosphere. The temperature θ_0 is therefore given, and the efficiency can only be increased by diminishing τ_1.

The following table is calculated from (eq. 486) for different values of $\frac{p_1}{p_0}$ the temperature of the compressed air at entering the working cylinder being taken $\theta_0=293°$, that is, 20° C.

TABLE IV.

$\frac{p_1}{p_0}$	E.	$\frac{p_1}{p_0}$	E.
2	.82	9	.53
3	.72	10	.51
4	.67	11	.50
5	.63	12	.49
6	.60	13	.48
7	.57	14	.47
8	.55	15	.46

The table shows that when the pressure has reached four atmospheres, even a considerable increase of it does not much effect the efficiency.

II.

MAXIMUM EFFICIENCY CALCULATED FROM THE INDICATED WORK.

Let P=the pressure of the compressed air,

Let p=the pressure of the atmosphere,

V and v=the corresponding volumes; also let $P=np$; then $V=nv$.

The work spent upon the air to compress it, is, (eq. 26),

$$W_1=pV \text{ nap. log. } \frac{V}{v}=pV\times 2.303 \text{ com. log. } n$$

The work performed by the air is :

$$W_2=(P-p)v,$$

and as $Pv=pV$, and $V=nv$, we have

$$W_2=pV\left\{1-\frac{1}{n}\right\};$$

hence,

$$E=\frac{W_2}{W_1}=\frac{pV\left\{1-\frac{1}{n}\right\}}{pV\times 2.303 \text{ com. log. } n}=\frac{\left\{1-\frac{1}{n}\right\}}{2.303 \text{ com. log. } n} \qquad (49.)$$

Substituting different values of n in this formula we get the corresponding values of E.

III.

THE EFFICIENCY OF COMPLETE EXPANSION AND OF FULL PRESSURE COMPARED.

To show the comparative merits and demerits of full pressure and complete expansion in the use of compressed air, we present a table prepared by M. Mallard.

(*See Table on following page.*)

The initial temperature is assumed at 20°C.

The table shows that by working non-expansively we avoid very low temperatures of exhaust; but this is of little practical importance when we take into account the low efficiency of full pressure, as compared with complete expansive working. Also when working at full pressure, the higher the working pressure the lower the efficiency.

CHAPTER VII.

THE EFFECTS OF MOISTURE, OF THE INJECTION OF WATER, AND OF THE CONDUCTION OF HEAT.

I.

GENERAL STATEMENTS.

In dealing with compressed air we must always keep in view the very important consideration of the *initial* and *final temperature* of the air.

There are two principal causes tending to vary the amount of heat present in the compressor or absorbed in the working-cylinder:—

1. The water or water-vapor of which atmospheric air always contains more or less, and which is purposely introduced

TABLE V.

$\frac{p_2}{p_1}$	Final temperature. Degrees C. Complete expansion.	Theoretical efficiency with complete expansion.	Final temperature. Degrees C. Full pressure.	Theoretical efficiency with full pressure.	Ratio of efficiency at full pressure to efficiency at complete expansion.
2	— 33.4	.855	—22.4	.82	.95
3	— 60.0	.806	—36.9	.72	.90
4	— 77.0	.782	—43.2	.67	.86
5	— 89.0	.768	—48.0	.63	.82
6	— 98.0	.758	—51.0	.60	.79
7	—106.0	.751	—53.0	.57	.74
8	—112.7	.746	—54.5	.55	.73
9	—118.1	.742	—55.6	.53	.71
10	—122.9	.739	—56.5	.51	.69
11	—126.9	.736	—57.4	.50	.68
12	—130.5	.734	—58.0	.49	.66
13	—133.8	.732	—58.6	.48	.65
14	—136.7	.730	—59.2	.47	.64
15	—139.4	.729	—59.5	.46	.63

into the cylinder of the so-called wet-compressors.

2. The conduction of heat by the cylinders, supply-pipes, reservoirs, &c.

II.

THE EFFECTS OF MOISTURE.

Atmospheric air always contains more or less moisture. We wish to consider the effects of this moisture upon the air undergoing compression or expansion. The injection of water into the cylinders and its cooling or heating effects are left out of the question altogether, as they will receive attention further on.

In all conditions of temperature and pressure practically realizable, a mixture of air and saturated water-vapor will remain saturated when the mixture expands against a resistance, a certain quantity of water being thereby condensed; on the contrary, compression superheats the vapor, which then becomes non-saturated, and non-saturated vapors follow the laws of permanent gases.

1. *Influence of water-vapor upon the work spent on the air and upon that performed by it.*—The presence of moisture in the air has been found to be favorable both in the compressor-cylinder and working-cylinder. In both cases, however, the gain in work spent or performed is so slight that it can be entirely neglected, and the formulas already established for dry air become applicable with a sufficiently close approximation. In the case of compression, the vapor is superheated and therefore comports itself very much like the air itself; while in the working-cylinder, the increase of work performed, when the initial temperature of the compressed air does not exceed 30° C., is very small; and, as the temperature at which compressed air is used, is rarely higher than 20° C., the influence of the water-vapor can be safely neglected.

2. *Influence of the moisture of the air upon the Final Temperature.*—The presence of the moisture in the atmospheric air introduced into the compressor tends to lessen the heat of compression; this effect, however, is very slight, and, in a practical point of view, is not worth considering.

When compressed air is completely expanded in a working-cylinder, the presence of moisture in it tends to lessen the cold produced. M. Mallard has found what the initial pressure would be for certain initial temperatures, so that the final temperature should not fall below 0° C. He has found this for both dry and saturated air, and his results are tabulated as follows:—

(*See Table on following page.*)

This table shows that, if compressed air at 50°C and at a pressure of three atmospheres be introduced into a working-cylinder, this air, if saturated with aqueous vapor, can be completely expanded without falling to a temperature below 0°C; and that this air, if dry, dare

TABLE VI.

Final temperature. Degrees C.	Initial temperature. Degrees C.	Value of $\frac{\psi_0}{\psi_1}$ with the air.	
		Saturated with water-vapor.	Dry.
0°	20°	1.50	1.276
0°	30°	1.89	1.432
0°	40°	2.39	1.602
0°	50°	3.06	1.780

not exceed an initial pressure of 1.78 atmospheres if its final temperature is not to fall below 0°C.

3. *Volume of the Cylinders.*—This is calculated as for dry air, since the effect of the moisture is too slight to be taken into account.

III.

THE INJECTION OF WATER.

1. *The Effect of Introducing Water into the Compressor-Cylinder.*—It is of great advantage in practice to introduce cold water into the compressor. It carries away the heat of compression to a very great extent. It acts as a lubricant, and, by cooling the cylinder, it prevents the destruction of any organic material, such as packing, valves, &c., that may be employed upon it.

If in addition to the atmospheric moisture present in the air at its entrance into the compressor, water be introduced in quantities just sufficient to keep the air saturated with water-vapor during the compression, the work spent upon the air and the final temperature at the end of compression will both be less than if the air had not been kept saturated while being compressed. It is unnecessary to calculate the amount of work saved or the extent of temperature reduced by the presence of this saturated water-vapor; for if water is at all to be introduced into the compressor, it may as well be thrown in in larger quantities, that is, in quantities sufficient to absorb and to carry off the greater part of the heat of compression.

The effects of the heated air in the compressor is a great cause of loss of motive power, and it is very desirable to cool the air during its compression.

The final temperatures for different pressures have already been given in Table II. We repeat them here in connection with the quantities of work spent when the compression follows Boyle's law and when it is effected without any removal of heat.

TABLE VII.

Tension in atmospheres.	Compression with temperature constant.		Compression with increase of temperature.			Loss of work due to the heat of compression. kilogram-meters.	Fraction of the total work required for compression, which is converted into heat.
	Volume in cubic meters.	Work in kilogram-meters.	Temperature in Degrees C.	Volume in cubic meters.	Work in kilogram-meters.		
1	1.00		20°	1.			
2	.50	7,199	85°.5	.612	7,932	733	.092
3	.333	11,356	130°.4	.459	13,360	2004	.150
4	.250	14,260	165°.6	.374	17,737	3477	.196
5	.200	16,580	195°.3	.320	21,209	4629	.213
6	.167	18,475	220°.5	.281	24,310	5835	.240
7	.143	20,038	243°.2	.252	27,048	7040	.260
8	.125	21,422	263°.6	.229	29,518	8096	.274

The Quantity of Water to be Injected.—We have found eq. (26), that the quantity of heat developed by compression is given by the formula,

$$Q = \frac{R\tau_0}{J} \text{nap. log.} \left\{ \frac{v_0}{v_1} \right\},$$

where τ_0 is the absolute final temperature $=273°+40°=313°$. From this formula the quantity of heat, Q, is calculated for different pressures. We then find the weight of water, which, if introduced at 20°C and removed when it has taken up enough heat to raise its temperature to 40°C, would absorb this quantity of heat Q. Under these conditions we find that

each kilogramme of water will absorb 20 calorics. Dividing Q by 20 we get the weight of water to be introduced in kilogrammes. In this way the following table was prepared:

TABLE VIII.

Absolute pressure to which the air is compressed.	Heat developed by compression and to be carried off by the injected water.	Weight of water at 20° C. to be injected into the compressor per kilogramme of air compressed in order to keep the final temperature from rising above 40° C.
atmospheres.	calories.	kilogrammes.
2	14.695	.734
3	23.284	1.164
4	29.392	1.469
5	34.120	1.701
6	37.979	1 891
7	41.264	2.063
8	44.087	2.204
9	46.589	2.329
10	48.816	2.440
11	50 849	2.542
12	52.694	2.634
13	54.391	2 719
14	55.962	2.798
15	57.425	2.871

2. *The Injection of Hot Water into the Cylinder of the Compressed-Air Engine.*—In the production of compressed air, the great cause of loss of motive power, as we have seen, is the development of heat. Analogous to this is the loss which occurs in the *use* of compressed air. Great cold is produced by expansive working, and this has long forbidden its adoption. The injection of hot water into the working-cylinder, has now made it possible to attain the desirable result of working expansively.

The Quantity of Hot Water to be Introduced.—The quantity of heat, Q, to be supplied to keep the temperature of the expanding air constant is found from eq.(26), to be,

$$Q=\frac{Rr_0}{J}\text{ nap. log.}\left\{\frac{v_1}{v_0}\right\}.$$

The expansion being supposed to follow Boyle's law, we have,

$$p_1v_1=p_0v_0,\text{ or }\frac{v_1}{v_0}=\frac{p_0}{p_1}$$

Hence we have,

$$Q=\frac{Rr_0}{J}\text{ nap. log.}\left\{\frac{p_0}{p_1}\right\}.$$

$p_1=1$ in this case since the air is expanded down to atmospheric pressure. From this formula the weight of water to be injected is calculated as in table. The results are given in the following:

TABLE IX.

Absolute pressure at which the compressed air is introduced into the working cylinder.	Quantity of heat to be supplied to keep the temperature of the air from falling below 0° C. during its expansion down to atmospheric pressure.	Weight of water to be injected into the working cylinder per kilogramme of compressed air introduced to keep the final temperature from falling below 0° C.		
		The temperature of the water introduced being		
		20° C.	50° C.	100° C.
2	13.280	.134	.103	.074
3	21.030	.212	.163	.117
4	26.550	.262	.206	.148
5	30.828	.311	.240	.178
6	34.334	.346	.266	.192
7	37.285	.376	.289	.208
8	39.833	.402	.309	.223
9	42.094	.425	.326	.235
10	44.106	.445	.342	.247
11	45.945	.464	.356	.256
12	47.612	.480	.369	.266
13	49.145	.496	.381	.274
14	50.562	.510	.392	.282
15	51.885	.524	.402	.290

The quantities of water here given are the minima values since the latent heat which is released by the water in freezing has not been taken into account. Hence

to avoid the formation of ice we must add a slight excess of hot water.

3. *The Effect of the Conduction of Heat by the Cylinders, Pipes, &c.*—Since the temperature of the compressed air when used is most always that of the surrounding atmosphere, the result of the conduction of heat by the containing vessels is the dissipation of the total heat of compression. The mechanical equivalent of this heat is, of course, lost work, and, as it is most economical to get rid of this heat during compression, conduction and radiation from the compressor is an advantage. Since, in working expansively, there is a tendency for the cylinder to become colder than surrounding bodies, the conduction and radiation of heat is here too, if anything, an advantage.

In all our formulas and results hitherto established, the cylinders have been supposed non-conducting; and the investigations of M. Mallard have shown that this hypothesis is justified. For the heat leaving the compressor by conduction and radiation is in part compensated for by that developed by the friction of the piston; and the heat conducted through the working cylinder is very small relatively to that converted into work. Hence, any passage of heat by conduction of the cylinders belongs to those secondary quantities which are always omitted in the general theory of motors, except so far as allowed for by proper coefficients.

CHAPTER VIII.

American and European Air-Compressors.

I.

PUMP COMPRESSORS.

Pump or plunger compressors are generally in high repute in Germany and Austria, especially in mines, and they seem to give very satisfactory results. In the United States they never have been used to any considerable extent and are now not at all used.

It must be said to the prejudice of these compressors, that, in consequence of the large mass of water to be pushed back and forth by the plunger, a large per-cent. of power is wasted in overcoming inertia; that high piston speeds are, in consequence of the violent shocks which result, utterly impossible; that they are very heavy and hence require expensive foundations; that when the prime mover is run at a high speed, a more or less cumbrous, expensive, and wasteful machinery of transmission is necessary; that their use is limited, pressures of 5 or 6 atmospheres being their utmost capability, on account of the large quantity of cooling water taken up by the air at even moderately high tensions; that a large amount of cooling-water is required to produce a comparatively small effect in the abstraction of heat.

On the other hand, it must be admitted that these compressors are liable to very few repairs, that they are simple in construction and that "dead spaces" are avoided.

The hydraulic or ram compressors first used by Lommeiller at the Mt. Cenis Tunnel have become obsolete.

II.

SINGLE-ACTING WET COMPRESSORS.

The air compressors now used in the United States are either "*Dry Compressors*" in which the cooling is effected by flooding the external of the cylinder, and sometimes also the piston-rod aid-head, with water; "*Wet Compressors*," by the injection of water into the cylinder-space, as well as by external flooding; *compressors* with *no* cooling arrangement are seldom used, and only in temporary and cheap plants.

Compressors with a partial injection of water have been used to very good effect in the United States. Most of these are single-acting, and are represented by the machines of Burleigh, of Fitchburgh, Mass. The cooling is very efficient and hence the useful effect is considerably increased. They are very durable and not liable to get out of repair, as is shown by the record of Burleigh's machines which have stood the test of years of steady work.

The use of single-acting compressors renders it necessary that, in all cases where anything like a uniform supply of air is needed, to have two compressor-cylinders. These cannot be driven directly from the piston-rod of the driving engine, but necessitate an indirectly coupled-connection of some sort.

All this makes single-acting compressors somewhat cumbrous and expensive.

As built to-day, the evils of dead spaces, and of jars and shocks resulting from water in the cylinder, have not been duly considered. There are also a few cases when the sectional area of the inlet-valves is insufficient; and in general those parts which are most liable to get out of repair are most difficult of access.

We are inclined to think that the claim of the Burleigh Co., that their compressor is the most efficient, economical, and durable of any built in this country, cannot be far from the truth.

III.

DOUBLE AND DIRECT-ACTING COMPRESSORS.

Up to within several years ago, single-acting compressors have been used almost exclusively. Now the double and direct-acting compressor seems to be superseding it. This is now the leading type of American compressor, although hitherto it has given at least no better results than the best single-acting machine.

Superiority in the double-acting compressor is found in its simplicity. The piston of the engine drives the compressor by a direct connection. All wasteful and cumbrous machinery of transmission is at once unnecessary and high piston-speeds are possible; in the United States from five to seven feet.

Most American double and direct-acting compressors are of the dry kind. These have the advantage that the air is delivered without having any water mechanically mixed with it. Hence very much ice cannot be formed when the air is worked expansively. Higher rates of expansion are possible than with air from a wet compressor.

One of the very best American double and direct-acting dry compressors is the "National," built by Allison & Brannan, Port Carbon, Pa., (Office, 95 Liberty St., N. Y.). Steam cylinders of the medium sized duplex machine are $12'' \times 42''$, and the air cylinders $15'' \times 42''$. The air pistons work to within one sixteenth of an inch of the cylinder heads. The water circulation for cooling passes spirally around the air cylinder from the center to each end. The engine will compress air to the same pressure as that of the steam used. The amount of free air compressed at a piston speed of 350 feet is about 1000 cubic feet per minute. A greater pressure of air than the pressure of steam used is obtained by increasing the size of the steam cylinder, or decreasing that of the air cylinder.

The best double and direct acting compressor of the wet kind is undoubtedly that of Dubois Francois, built in Seraing, Belgium, and exhibited at the Centennial Exposition, in 1876.

Dry compressors, although the cheapest as regards first cost, are not the most economical in working. But where air is to be carried through pipes exposed to great cold they are the only alternative.

IV.

DESIGN AND CONSTRUCTION.

The efforts of builders and engineers should be directed to the attaining of a higher efficiency, and they should not, as is now often the case, sacrifice the latter to cheapness and small dimensions. To attain such desirable efficiency the heat of compression must be more effectually abstracted. This must be done by a more ingenious and rapid circulation of water around the cylinder, and injection of water in the form of spray into the cylinder. But the injection of water in some efficient and practical manner, which is so essential to the reaching the highest efficiency, introduces the great disadvantage of having to work with wet air. Hence we see how important would be an invention of means or apparatus for separating the water from the air when direct intercontact has been had to keep down the temperature. We must also remember the important physical fact that water absorbs very considerable volumes of air—volumes dependent upon the pressure of the air and the amount of surface of water exposed to the fluid contact, time being also an important factor.

Clearance must be reduced to the smallest possible amount. It has been brought down in a few cases to 0.39 inch. A long stroke, one from 2 to to 3 times the diameter of the cylinder, is another means of avoiding loss from dead spaces, since here the air which fills the dead space is small in comparison with that actually delivered. The

valves must be so placed that, between their seats and the piston-head at the end of the stroke there shall be the smallest possible clearance.

The valves themselves, to close the more rapidly, are made to have only a very small travel. (This has been made as small as .08 to .12 inch.) The valve-area must be made large enough by increasing the number of the valves. The valve-area should be amply large, generally from $\frac{1}{8}$ to $\frac{1}{10}$ of the sectional area of the cylinder. The valves should be so attached to the cylinder head that they may be removed and repaired without taking off the latter or otherwise taking the machine apart.

Great care must be taken to have the piston head fit the cylinder accurately and closely, since, especially in dry compressors, great losses result from any looseness. The piston-heads should be made so that they can be adjusted to preserve a nice fit, as in steam engine practice. Lubrication of the cylinder in case of the dry compressor should be effected by automatic oil cups placed upon it.

It must also be borne in mind that the working pressure is that which most influences the physical conditions of working, and the suitable mode of construction. And, although the loss of work increases with the pressure, yet the *rate of variation* of the loss of work decreases as the pressure increases. As great a proportion of work is lost by increasing the pressure from two to three atmospheres as by increasing it from five to ten atmospheres.

The tendency in Germany and France, as well as here, is for the wet compressor entirely to supersede all others. But it is scarcely too much to say that the air-compressor of the future has yet to be invented.

CHAPTER IX.

Examples from Practice.

I.

The Republic Iron Company of Marquette, Mich., have done away with the use of steam, by utilizing the power of a water-fall situated about a mile from their works. The power is transmitted by means of compressed air which drives all their machinery, and thus saves the cost of fuel.

There are four compressors, 24″ diameter and 5′ stroke, driven by two turbine Swain water-wheels 5½′ diameter, under 16 feet head of water. As near as has been ascertained, they have about 450 horse power at the wheels. The air is carried one mile in a pipe built of boiler iron, 15″ inside diameter. About 66 per cent. of the effective power of the wheels is obtained at the mines and shops.

II.

Economy promoted by the use of compressed air.

To show the great saving of both time and money since the introduction of compressed-air machinery we will give a few figures.

It cost the Golden Star Mining Co., of Sacramento $12 to $15 per foot to run a tunnel 7×7 feet when employing hand labor; after introducing air machinery it cost them $6 to $7 per foot; with hand labor they made a distance of two feet per day; with machine labor, a distance of six feet per day.

Another instance, among many, is that of the Sutro Tunnel Company of Nevada;

Expense by hand labor per month	$34,000 to $50,000.
Expense by machine labor per month	$14,000 to $16,000

III.

Compressed-air motor street car.

The pneumatic engine which has been on trial by the Second Avenue Railroad Company, on the Harlem portion of their road, from the Station at Ninety-Sixth Street, to Harlem River, at One-Hundred-and-Thirtieth Street, has proved so satisfactory to the company that it has authorized the construction of five more engines.

These are to be used exclusively on the upper part of the road, where it is proposed to dispense entirely with the use of horse power, so soon as the requisite number of engines shall be procured. It was stated at the company's office yesterday that the most sanguine expectations had been fulfilled; the new engine could be run at a trifling cost, and without the noise and smoke and

smell of oil which accompany the use of steam; any rate of speed which was likely to be required could be maintained, and the engine was under as complete control of the engineer as one propelled by steam or a car drawn by horses. It was not known whether any change was proposed below the station at Ninety-Sixth Street; certainly none at present.

The new engines are manufactured by the Pneumatic Tramway Engine Company, whose office is at No. 317 Broadway. Some time ago two Scotch engineers, Robert Hardie and J. James, invented a system of propelling cars by means of compressed air. The invention was examined by a number of practical railroad men who were visiting Scotland. Hardie and James were induced to visit this country and the company was organized. Experiments have been making for a year, resulting in improvements which now seem likely to render the invention serviceable to the public. The motive power is condensed air, contained in two reservoirs, placed one under each end of a car, which is similar in construction to those in ordinary use on street railways. The air is pumped in by a stationary engine at one hundred and twenty-seventh street, and this has been so far improved that the reservoirs in the cars now used are filled in a few minutes. These are of steel, and are tested up to a strength many times greater than their working pressure, and it is claimed that there is no danger of explosion. The machinery is simple and not liable to get out of order. The air-tanks of the experimental car are only sufficiently large to enable it to make one round trip between Harlem and Ninety-Sixth Street stations; but the cars now building will be larger and will contain reservoirs of much greater capacity; and it is claimed that there will be no difficulty in constructing them so that the round trip from Harlem river to Peck Slip can be made without replenishing.

Mr. Henry Bushnell, of New Haven, is the inventor and constructor of a new compressed air motor street car, the chief peculiarity of which is that he is able to force air into his receivers until his gauge registers the enormous pressure of more than 3,000 pounds per square inch. His receivers are tubes, the largest of which are twenty feet long, and only eight inches in diameter, inside measurement. There are four of these, two lying side by side above the axles, and next to the wheels on either side of the car. Between them at one end are four other tubes, each six feet long and six inches in diameter, inside measurement. The material is wrought iron three-eighths of an inch thick, and are welded in. The double cylinder engine which utilizes this air in turning the wheels of the car does not differ materially from a steam engine, except that its two cylinders are only two and three-fourths inches in diameter, inside measurement. The machine built by Mr. Bushnell to compress the air consists of three steam air pumps. The first and largest is merely a feeder to the second. The air that comes from it is condensed to a pressure of about six pounds. This denser air is more worthy the prowess of the second pump, which in turn crushes it into a greatly smaller compass. The third pump gives the final pressure. The gauge on the compressing machine has registered 3,500 pounds per square inch. The plungers of the second and third pumps have no heads. They are merely rods of steel forced into vessels containing oil. As the plungers move out and in, the surface of the oil falls and rises, admitting the air through one valve and forcing it out of another. It is, therefore, necessary to have the packing of the plungers only oil tight, not air tight, under the tremendous pressure. Air, like all other substances, gives out heat while being compressed, and it is necessary to cool the chamber that first receives the air from the third pump by a covering of cotton waste saturated with water. On the other hand, the expansion of the air as it is given off at each half revolution of the car engines absorbs heat, and after running the car for a short time the engine cylinders and escape pipes are whitened with frost. This coolness destroys in part the elasticity of the air as it enters the cylinders. To remedy this Mr. Bushnell will surround the cylinders with stout metal jackets, beneath which he will force air with the aid of a small pump geared to the machinery of the car. This newly-compressed air, he says, will supply heat enough to keep the cylinders warm.

The writer rode recently on the new car as far on the Whitneyville road as Mr. Bushnell could go without interfering with the trips of the horse cars. The motion was easy, and at times about twice as rapid as that of a horse car. The new vehicle obeyed the engineer promptly in starting and stopping. The distance traveled in going and returning was a little over a mile. At the start the guage registered 1,800 pounds. At the return the pressure indicated was 1,500 pounds. When the air was allowed to escape from a turned cock the roar was frightful and was as irritating to the ear as escaping steam. In running, however, very little noise is heard from the escape-pipe, because the escaping air is made to pass through a mass of ordinary curled hair. This device Mr. Bushnell esteems one of the most important of his inventions. He has no doubt that it would prove equally efficacious in deadening the sound of escaping steam.

Friends of Mr. Bushnell claim that he could never make a receiver capable of retaining air at the high pressure he had in view. The air that was in the tubes last Thursday was pumped in, he says, on the 25th of June. The gauge then showed 2,100 pounds. The pressure gradually lessened until two weeks ago, when it was 1,900. After that time a small leak was discovered. This leak was closed with a turn of the wrench, and after that not a pound was lost up to the trial, when 100 pounds was allowed to blow off to gratify the curiosity of visitors just previous to the short trip referred to.

Mr. Bushnell called attention to the small diameters of his largest tubes. He said that a pressure of 2,000 pounds per square inch would give, by calculation on the head of each tube, an aggregate pressure of fifty tons; while the two-feet heads used by the inventor of a rival compressed air motor would have to withstand an aggregate pressure of 180 tons, if a pressure of 800 pounds per square inch should be put on, as the inventor claimed was possible. The heads were necessarily the weakest parts of the tubes. A welded joint, such as his were, was usually reckoned twice as strong as a riveted one.

On a previous occasion Mr. Bushnell made a round trip on his car on the Whitneyville road, a distance of a little over four miles. The pressure was then reduced from 1,950 pounds at the start to 750 pounds on the return. A company called the United States Motor Power Company has been formed, and Mr. Bushnell is its president.

ARCHITECTURAL CEMENTS.

From "The Engineer."

PORTLAND cement has unquestionably proved a most important gift to the architect and builder. Viewed æsthetically it was an immense advance upon the ugly red-brown "Roman" cement of Parker; still, as an ornamental material for plastering external surfaces, and casting into decorative forms it has some grave defects. Chief of these to the artistic mind is its cold ashy grey color, and the minutely porous texture of its finished surface, which is rapidly rendered darker and more gloomy-looking by the deposit in its innumerable porosities of minute particles of London smoke and soot. Portland cement makers have speculated in a desultory manner upon the great improvement which would be effected, if materials could be found not requiring more expensive manipulation than those necessary to produce the existing cement, but which should yield a product having a more sunny tint than the cold leaden color of Portland cement, one, in fact, more nearly resembling the actual shade of a clean building of the best Portland or Bath stone. There are some considerable difficulties in the way of introducing such an improvement, for so intense are the coloring powers of the peroxides of iron and manganese in combination with the earthy bases and with silica, that a mere trace of either or both of these oxides is

sufficient to remove all whiteness or purity of tint from cements produced from the materials ordinarily employed. The glass manufacturer, and to a considerable, though less extent, the brickmaker, can largely remove or greatly modify in the processes of fusion or of kiln-burning the tints of their manufactured articles; but the processes employed by the glassmaker are too delicate and expensive to be applied to the decoloration of the materials of cement, and the direction for improvement must rather be looked for in the scientific choice of the materials themselves than in any chromatic changes to be wrought in them during the processes of manufacture. In France some progress has been made in this direction. In the south a manufactory which still bears the historical name of Vicat, situated not far from Grenoble, produces, from combinations with the limestones of Dauphiny, a plastering material which has really the sunny color of those softer varieties of Bath stone which were so largely applied by Sir William Chambers and his successor, Gandon, to internal decorative carving, fine examples of which may be seen in the interior of Chambers' noble structure, the Custom-house of Dublin. It is stated on good authority that amongst the multitudinous beds of calcareous stone which crop out along the coast around Boulogne, one or more thin beds of a very light yellowish color are found which produce a cement of the desired bright tint. There are immense Portland cement works at Boulogne, but the demand is chiefly for constructive purposes upon a great scale, and little attention seems to be there given to the fineness of tint of the cement, and a very small rival manufacturer, who, we believe, was the discoverer of these fine tinted beds, was stopped by his colossal rivals, who purchased the deposits from under his feet. It may be noticed also, that in Ireland—where, as yet, we believe, all the Portland cement employed is imported, none being manufactured—there is an immense assortment from which to select suitable argillaceous limestones. These are to be found in various localities—more especially in the tilted up beds which are found cropping out at highly inclined angles for several miles to the westward of Drogheda, along the northern bank of the river Boyne. Scarcely two of these beds are quite alike in composition. There are thick beds of almost pure crystallized carboniferous limestone, and there are hundreds of various composition, none being very massive, running into limestones so clayey and siliceous that they will not burn into lime at all in the ordinary kiln. During the presidency of the late Sir John Burgoyne, as chairman of the Board of Public Works of Ireland, at a time when hydraulic lime equal in quality to that of Aberthaw was largely needed for the works of improvement then going on upon the river Shannon, a member of the Board, Mr. Radcliffe, conducted for his own information an extensive but desultory series of experiments upon the diverse calcareous minerals of Ireland that might produce hydraulic contents, and amongst these many of the beds along the Boyne were subjected to experiment, and some produced hydraulic cements of considerable hardness, and of great beauty of color. Mr. Radcliffe, however, was no chemist, and had much of the red tape of his office to attend to, and often obtained through his scientific ignorance anomalous results which he could neither trace nor explain, and which at length disgusted him, and the further prosecution of the research was abandoned. A large body of data of more or less value was, however, collected, chiefly through the intelligent assistance of Mr. Charles Scanlin. The results obtained may, perhaps, still exist in the archives of the Board at Dublin. The circumstances have so far been here alluded to, however, because the immense repertory of calcareous and silico-aluminous beds remain, we believe, still to reward with success the energy and skill of whoever shall bring them into use. Their position, as above indicated, is favorable for the establishment of a cement manufactory, the materials being abundant. Coal, though imported, is nearly as cheap as anywhere else in Ireland, and the means of distributing the manufactured article are ready. A richly colored cement, having the other properties of Portland, would soon command a large sale and introduce a new manufacture almost wholly from native

materials, to Ireland, which at present can boast of little else in the way of manufactures, except those of porter and whiskey.

Another cement is conceivable, of a decorative character and nearly colorless or pure white when in mass, which would seem eminently worthy of attention, to produce which, however, we must look in another direction than to the sedimentary rocks. Calcareous minerals, as chalk, and the white marble of Donegal, are easily obtained. The difficulty begins when we look for a material containing soluble silica in abundance, and freed from the discoloring elements of iron and manganese. Now, amongst the secondary products of volcanic districts, we have a source, as good as it is inexhaustible, of what we need. Almost all lavas, but especially the colorless, or but slightly colored trachytes, when exposed to the vapors which are exhaled from the fissures called fumaroles, are well known to all who have visited the popular wonder of the solfatera near Pozzuoli. The vapors, emitted in all similar fissures in volcanic districts, of hot steam mingled with the vapor of hydrocholoric acid, and of sulphurous acid, slowly passing by higher oxidation into sulphuric acid, act with surprising energy in reducing the hard crystalline trachytes into a soft, plastic, and often colorless mud, and by further decompositions frequently into hyalite, which in the lapse of time becomes converted into various varieties of opal, as found now in the great tufa beds of the extinct volcanic regions of Hungary. These decompositions and their results are seen in a vast scale in the siliceous linings of the Geyser basins in Iceland, in New Zealand, and in that wonderful natural volcanic museum, the national or people's park of the future, in California. In any quantity these natural compounds of more or less soluble silica, and as colorless as ice, may be had for the trouble of collection and transport. With pure limestone, and with these remarkably pure hydrated silicas, in composition with more or less of equally pure alumina, it would seem quite practical to procure a cement for internal and perhaps external decoration of dazzling whiteness and beauty, and which from its closeness of texture would not become discolored by the coal smoke of our cities, and which would bear washing whenever necessary. The eyes become so habituated to the roughish and *grenu* surfaces of Portland and other building stones as well as of cement, that fancy suggests that a fine smooth close-grained surface for the exterior of our buildings is unsatisfying to the eye. Any one, however, who will examine the façade of a large building—a bank, we believe—in Cockspur-street or Trafalgar-square—we know not which it should be called now—nearly facing and to the south-west of the Nelson column, which has been constructed of Sicilian white marble, may easily see that a smooth, hard, white external surface is quite consistent with architectural beauty, and possesses immense advantages in the smoky atmosphere of London.

For internal decorative purposes it would be needless to enlarge upon the value of a material that would possess far greater beauty in color and texture than plaster of Paris; would be non-absorptive, little attractive of smoke, not easily scratched, and which might be washed again and again. Every one who has examined the interior of the decorated rooms of Roman villas at Pompeii will have been struck by the smoothness, density, and hardness of the colored surfaces of stucco, upon which the plain color and fresco paintings of the walls have been laid. The common belief is that this stucco has been mainly formed of lime mortar, more or less mixed with *gesso* or plaster of Paris. We are, however, by no means convinced that the true composition of the material has been revealed by the imperfect analyses and carless examinations of modern times. It is somewhat difficult to obtain specimens for examination, for every morsel, however fragmentary and valueless, of this or of any other material to be found in the rubbish heaps of Pompeii is rigidly prevented by the guardians from being removed by the visitor who can only secure a specimen by the troublesome and round about process of obtaining an official order from Naples. The observer is, however, struck by the remarkable fact that polished fragments of various different and brilliant colors abound in the rubbish heaps of Pompeii which, after

eighteen hundred years' exposure to air and moisture, and to the corrosive vapors which everywhere permeate the porous soil about Vesuvius, are as hard, smooth, and brilliant as when they left the hand of the workman. A more careful examination than has yet been made of these stuccos might yet reveal the process of their formation, and perhaps show that the soluble silicates produced by secondary volcanic reactions, such as we have spoken of, were employed in their formation.

The economic uses to which several volcanic products may be applied open a vast and, as yet, almost untrodden path of useful discovery. One of the valuable uses to which these may be employed is largely known to the house decorators of Rome and Naples. Certain trachytes when fully decomposed by fumarole vapors, finally fall into an impalpably fine and soft powder without coherence, of various beautiful delicate pearly-white tints, which are used as the coloring material for ceilings and plastered walls in place of whiting when applied with size. The character of delicate and slight broken color thus given is greatly superior to the eye of taste, to the cold dull white of our whitened ceilings and walls. It is also in texture much more satisfactory to the eye. The lime beds of tufa which abound around Vesuvius and in Auvergne, are to be found of every color and tint, from pure white, such as is the "domite" of the Puy de Dôme, to buff, yellow, red, and brown, into almost coal black; indeed all these tints occur together in super-position in the masses of tufa, generally of impalpable fineness, over which one ascends to the crater of the volcano in the Lipari Island of that group. A miserable, abortive attempt has for many years continued a struggling existence to extract such chemical substances as boracic acid, sulphur and alum, from the ejecta of volcanoes, but neither these, nor, so far as our knowledge extends, in any other volcanic district in Europe, has any well-considered attempt been made to utilize for architectural or other economic purposes the vast deposits of colored and pulverulent tufas—unless, indeed, we except the use made for the production of an hydraulic cement from certain tufas which are dug out by excavating into certain parts of the huge cone of Sarconi, in Auvergne. There can be little doubt that many volcanic tufas would consolidate by mere mechanical pressure, and a little baking into tessaræ, of various sizes that might be employed for laying ornamental mosaic flooring of much greater beauty and far cheaper than our English encaustic tiling, which by the large size of each tile, in proportion to the apartment which they floor, and the harsh and gaudy coloring but too generally offend a cultivated eye. Whether these or any other tufas would *per se* by pressure alone become sufficiently hard and coherent or not, it does not admit of doubt that by suitable admixture with calcareous or siliceous matter, or both, they would become so. The manufacture would be well suited to Italy and Central France. In Great Britain we are fortunately exempt even from dying-out volcanic action, although we have in the products of remote geological epochs, especially in the North of Ireland, abundant beds of lavas and trachytes which would readily suffer decomposition into soluble silicates if exposed to sol fatara vapors.

May we not artificially produce and utilize these vapors? Hot steam we can have at the expense of some coal. The alkali makers of Widnes, Glasgow and Belfast, as an educt of the process of decomposing common salt by Le Blanc's process for the purpose of making "salt cake," as it is called, and ultimately crystals of carbonate of soda, evolve millions of tons of hydrochloric acid vapor which used to fly into the atmosphere—until that nuisance was remedied by legal enactment—and the acid vapor compulsorily condensed to run into the sewers to waste. Sulphuric acid or vitriol is at hand in all these vast works as a necessary element for the decomposition of the chloride of sodium. We have here, therefore, on cheap terms, all the conditions requisite for the production of an artificial solfatara where we please, so that by the help of a little hot steam, hydrochloric acid, and sulphurous acid vapors commingled, we may at an extremely small cost decompose and convert into useful products such trachytes as may be found nearest and most suitable.

THE ORIGIN OF METALLURGY—THE BRONZE AGE.

From the French of EMILE BURNOUF, by CHRISTOPHER FALLON, A. M.

Translated for VAN NOSTRAND'S MAGAZINE.

I.

We are ignorant as to the date of the first appearance of mankind; we have no foundation upon which to rest the chronology of the primitive times. History dates only from yesterday, and yet, among the different nations, presents but fabulous origins. There is no more reality in the first facts related by Titus Livy than in the genealogies of the Grecian heroes. Adam and Eve are an agreeable myth, borrowed perhaps from Persia in the times of captivity; their descendents are the personification of families or of tribes. Grecian chronology goes back about six thousand years prior to our era, but is likewise preceded by a long mythological period. The same may be said of India and China. After all, what are six thousand years? Already have a hundred passed since the French revolution, and does it appear long to any one? Now-a-days events follow each other very fast and progress is rapid, because we possess forces, both physical and moral, of enormous power, by means of which we transform the earth and ourselves. When our ancestors possessed them not their advances were slow, their achievements small and casual. How can the ocean be traversed, or a large sheet of water crossed without boats, and how can we construct boats if there are no tools of iron or some substance sufficiently hard to work wood, to adapt the pieces and render them imperveable to water? Let us consider the objects we make use of to-day to clothe, shelter, nourish and convey ourselves from place to place, to procure light, heat, books and so many products of science and art which adorn our households. It will readily be seen that there is not one which does not suppose the possession and successful employment of the metals. We are now all aware that men have not known them at all times. For a great number of years, they did not possess any, except perhaps a few grains of gold which nature spontaneously gave them, and which they collected here and there on the banks and in the channels of rivers. It was this period which has been called *The Stone Age*, and the tools those unfortunate men have left behind them, as evidence of their industry and necessities, are all made of hard stone, of silex, of diorite, of absidian and of trachyte. This long period of the infancy of man is attested by the strata in which these objects are found, buried beneath mounds of earth which have required centuries for their formation; but the actual geological period had not yet begun when man was already in existence living among mammoths, bears in caves, and other animals now no longer to be found. . In the first place it was necessary that a man having selected a stone on which to put an edge, should strike it with another in order to scale it. Thus were the first hammer and the first hatchet made; and all other instruments being made in like manner, have given the name of *The Period of Unpolished Stone* to the era during which this rudimentary industry lasted. Little by little it was found that certain stones could by means of continued rubbing wear others, which were even harder, and so friction was substituted for percussion in the manufacture of tools. In this way sharp hatchets and scissors were made; round hard stones were bored and handles inserted. Smaller stones of finer quality or brighter color were shaped and pierced and then used as beads. Arms were made in the same way. It was this second period of humanity which has received the name of *The Period of Polished or Neolithic Stone.*

From the beginning, or at least from an early date, men attempted to mould clay into uses of different kinds. This work was done by hand during the entire age of stone. The potter kneaded the clay with his fingers, the impression of which is yet seen on the pottery of those early times. It required constant observation and new means of action to enable the potter first to discover the value of the movement of a wheel, and then to construct one. In fact the turn-

ing lathe seems to have been unknown during the whole period of which we speak, but the baking of vases dates far back, for from the time that men could light fires, they observed on their hearths pieces of argil become insoluble by the heat. The black, red or yellow clay which nature furnished them in many places, enabled them to color or paint these roughly made vases; they then polished the surface yet soft, by means of a stone burnisher and engraved fantastic figures thereon.

Then came the first metal, which let us say was the common metal, copper. The knowledge of gold certainly preceded that of brass, because gold is found in its natural state in many countries. It no doubt was the same with silver, the extractions of which is not very difficult; perhaps the same should be said of lead, for from the time globules of metal were found in the ashes of the fire, the man who noticed them, must have wanted to know the ore from which it was extracted, and having found it, must have sought for more in the mountains.

Substances which are producible in hearths, by the mere burning of minerals, must have been first discovered, as lead and glass; artificial glass, usually blue, is found among the objects of personal ornament of the most ancient times. On the other hand, when the extraction of a metal requires a high temperature, or a chemical operation, it may be conceded that such a metal was discovered long after the others and after a number of ineffectual attempts. Copper is found native, but in very small quantities; copper pyrites resembles gold, still the metal is obtained only by complicated operations, as is the case also with tin. Finally after obtaining these two substances, it is necessary, in order to form bronze, to make a fusion—which is attended with difficulties. The bare idea of uniting two metals does not readily present itself to the mind, and when once conceived it is yet essential to learn in what proportions they must be used in order to form a new metal, more useful than either.

Bronze appeared in the West when the art of polishing stone had arrived to a state of perfection. We have in our museums instruments of hard stone made anterior to the appearance of bronze, which our own workmen would not make better nor in any other manner; only they would probably make them faster, for they have means of action and processes which the ancients did not possess. Bronze, at first scarce, became more common in the course of time. Those fabricating it could dispose of it in other countries only in exchange for other objects of the same value but of a different kind. These objects of exchange caused a demand which could be supplied only by discovery, or by obtaining them elsewhere in sufficiently large quantities to give rise to commerce. The discoveries of which we are about to speak have proved that the quantity of bronze kept increasing, that with this new metal many instruments were manufactured which were previously made of stone, that new ones were invented, and that a time arrived when the substitution of bronze for stone was, so to speak, complete.

The Bronze Age was for a short time co-existent with the period of polished stone. There is then a period of transition when these two substances were, in a measure, blended together, and might be comprised under the same title in the age of stone or in that of bronze. It would be a mistake, however, to suppose that metal caused the hard stone to disappear entirely when the superior qualities of the former were discovered, as stone continues to be used for many purposes in many countries where neither bronze nor even iron has as yet supplanted it. Thus those small double-edged blades made of obsidian or silex, known as knives, still in use in the Grecian peninsula, in Asia minor, in Palestine, and no doubt in many other countries, are fastened to pieces of wood and used by the peasants to thrash their wheat or cut their straw. They are of the same shapes as in the bronze age and are made in the same way; but the predominance of metal over stone, and the abandonment of the latter, in most cases in which it was employed, characterize the long era which followed that of transition and which constitutes the bronze age properly so-called. In the same way that this metal was substituted for stone, it happened that a new metal concurred with bronze, and was used instead wherever there was a decided advantage in so doing.

Discoveries which were made only twenty years ago, and which since then have been repeated throughout Europe, have enabled us to fix the period of transition from bronze to iron. It differs from that which has been called the first age of iron, and which has, for a long time, been well ascertained. During the latter, iron already takes the first rank and awaits only to be brought to a state of perfection. The transitory period is marked by a slow and progressive substitution of the new for the old metal, and by a reciprocal influence from one to the other. When iron first appeared in Europe, it met the same fate which bronze a few centuries previously had experienced. It was a rare and precious substance and lost its value only by its increasing abundance, and when it could be converted into tools, utensils and arms, which were formerly made only of bronze. The oldest objects of iron found are bijoux and ornaments, for even in those early times there were rich and poor men, and those alone could obtain articles of iron who had other valuable objects to exchange. Do we not see the same thing in our own day? We assisted, a few years ago, if not in the discovery at least in the economical extraction of aluminum. This metal until then confined to laboratories, became an industrial product, but as the preparation is yet expensive it is worth twice as much as silver, and is employed in making ornaments and fancy articles. Yet it is not less common than iron in nature; it is the base of all clays and possesses qualities which can—which ought to make it preferable in certain cases to silver, to brass or even to iron. It needs but new processes of extraction to render it as abundant as the latter.

Iron has not entirely supplanted bronze, as the latter is still much used, nor would aluminum and all the other metals cause iron to be abandoned: but a new substance may answer many purposes better than those that have preceded it, and for this reason be preferred. For a long time hatchets were made of stone, but were set aside when they could be made of bronze; bronze hatchets were the only ones to be found for many centuries, but were also abandoned when iron ones became sufficiently abundant to compete with them in the market. The period of transition from bronze to iron is well characterized in many ways, of which we shall speak hereafter. There is no doubt, at present, of the reality of this change, and it is even becoming apparent how this transition was accomplished, the course the metals have taken to spread from one mart to another, until they have reached the most remote countries of Northern Europe; but before exhibiting these grand discoveries of our day, I must give an account of the progress which science has made in the study of ages anterior to any history.

II.

We need not here repeat the list of discoveries relative to the age of stone and to the men of those primitive times. The savants of the first empire and of the restoration had denied the existence of what was then called the fossil man. Science and religion united in discrediting even the mere possibility. The discussions which arose when Boucher de Perthes announced the discovery of the remains of such a man in the old alluvia of one of the northern departments, have not yet been forgotten. His discovery was followed by the sarcasm of some and the fanaticism of others, until the day when a new generation of savants recognized their authenticity. A short time afterward skeletons of fossil men and remains of their works were found on all sides. The name of Lartet is connected with the exploration of the caverns of Perigord and Languedoc; those of Tomsen and Wilson with the prehistoric antiquities of Denmark; and that of Keller with the lacustrial habitations of Zurich. Since then Boucher de Perthes is regarded as the originator of a new science, which forms the connecting link between the geology and archæology of historic times. This science though of recent date is always possessed of a great number of observed facts, is methodic and well defined, and its general results are already perceived. Among those who concurred in these first developments there will be found very few erudite men; they are mostly scientific men, geologists, physiologists, engineers, chemists, and perhaps amateurs who delight in this science as a past time to beguile their leisure hours

away. Texts were for a long time the only means of investigation; but the most ancient texts are, in reality, modern, if they are compared with those long periods of which mankind in its infancy passed over. The most ancient Grecian authors, those who under the real or fictitious name of Homer, have bequeathed the Iliad and Odyssey lived in the iron age, they related events which occurred many years before, and if real, were accomplished, according to all appearances in the bronze age. This does not prevent the author of the Iliad, and especially of the Odyssey to put iron in the hands of his heroes; thus the poets attributed to the past what was before their own eyes, but which the past never knew. Egypt had not yet begun to furnish those documents which are now being found; it was not known that the first four dynasties at least are anterior to the knowledge of iron in that country. The hymns of the Veda, to serve as scientific documents, should in the first place be classed according to a chronological order and referred, if possible, to certain and determinate epochs. India seems far from being able to throw any light on this subject. As to Genesis, it is known that its origin is a matter of discussion among the learned, and if some, true to their faith, attribute it to Moses, others reject its authenticity and consider it as formed by the union of two opposed traditions into one book. Be it as it may, and admitting the authenticity of Genesis, it is at least certain that its author had little knowledge of the bronze age, and still less of the stone age, for it is said that Tubal-cain, the first metallurgist who is mentioned, "was maker of all sorts of instruments of brass and iron." In fine, the ancient authors cannot have had correct ideas of the primitive times, composed perhaps of decades of years when writing was not yet in existence. It is possible there were traditions handed down from year to year, still the passage from the Prometheus of Eschylus, in which mention is made of the first men, of their living in caverns, and of the discovery of metals, is too vague to serve as a basis for scientific induction. In fact the ancients were not in a situation so advantageous as ours with regard to the past which there were no documents to record, as they neither had the means we possess, the innumerable facts which all the countries of the world can furnish, nor the capacity of acting in concert as now throughout Europe by means of communication and typography.

The Greeks made no underground searches. The Romans robbed a great many tombs, not through love of science, but to obtain the valuable objects therein, which have been reburied or have disappeared with them. The Roman church which followed the empire has never favored the positive sciences. The middle ages were taken up with metallurgy, but their end was that of King Midas; the philosophers stone was to convert all the metals into gold. The modern spirit which may properly be called the scientific spirit, after having learned with Bacon and Descartes its real rudiments has steadily advanced in a series of discoveries. Possessed of the abstract sciences it has been able to unite conjecture with reality, and found natural philosophy and chemistry.

It then gave birth to that new study, whose subject is human beings; to the physiology of plants, of animals, and finally to the science of man, of which prehistoric archæology forms the first chapter.

Farmers and workmen had for a long time known of the existence of instruments of bronze, and had gathered and sold them before the savants thought of collecting them and organizing a museum. The first collection made was that at Copenhagen. It was Thomsen who as early as 1836, classified all objects dug from the dolmens, barrows and mounds of Denmark, and founded the museum of Northern Antiquities, the finest prehistoric collection in Europe. A certain Swede, Sven Nilsson; profiting by Thomsen's work, and by his own knowledge of the barbarians of Oceanica and of other countries not yet civilized, united their industrial works with those of the ancient Danes, and from 1838 to 1843, introduced the study of comparative ethnology. It is not to be supposed that the savages of to-day are descendants of the ancient inhabitants of Europe, but their ways of life are the same, and they make use of the same means to satisfy their wants. There now exist colonies which do not know

the use of metals, or which obtain them in small quantities and look upon them as objects of personal ornaments; they have nothing to exchange in commerce with the rest of the world.

It was Thomsen and Nilsson who distinguished the stone age from the bronze age; they had found in the Northern countries a certain class of tombs in which, besides skeletons and rough pottery, objects of stone are found, but there were no traces of any metal. In others bronzes were found to have served the same purposes as stone, and to have been substituted. In others again appeared articles of iron almost similar in form to those of bronze of the other graves. It is evident that if the men of the first period had had bronze, they would have used it in preference to stone, while those of the second would have put aside bronze for iron.

Thus the first distinctions of the prehistoric ages were established and in succeeding years were confirmed. Two years after, M. Worsaae, a Dane, in his book on the ancient times of Denmark, set to work to explain the numerous discoveries of the bronze age made in his country. Notwithstanding this, until the year 1853 there were but few works added to the corpus of a science which seemed to be confined to Northern Europe. It is but necessary to recall the memory of Mr. Simon, of Metz, regarding the discoveries of Vaudrevanges near Sarrelouis; there were found four hatchets, one mould, one glave, one horse bit, fourteen bracelets, and many other small objects all of bronze. It was a real treasure, but added little new to the science.

Switzerland ranked next. In 1853 there were found in the lake of Zurich, and shortly after in the other lakes of that country, dwellings built on stakes driven in the ground, which have received the name of *palafittes*. With this discovery of great scientific value, we find the name of Dr. Keller associated. It confirmed those made in Denmark and Switzerland ten years previously. These houses were not situated along-side of each other, but superposed, and presented the three prehistoric ages. Among the ruins of the upper layer was found iron mingled with bronze; in the middle layers just beneath, bronze only together with objects of stone which the metal had not yet replaced; and lastly, in the lower layers on the bottom of the lake were found articles of stone only, without any metal whatever. At the same time the progressive march of civilization was noticeable by the excellence attained in the art of moulding either pottery or metal. There was no longer doubt as to the succession of ages, nor as to the essential character of each. The lacustrial habitation of Switzerland proved that these three periods of ancient civilization were not confined to the North, but were spread in more central countries.

That same year (1853), was favorable to the prehistoric sciences. While M. Keller was sounding the lakes of Switzerland, there was discovered at Villanova near Bologne, a necropolis, which has been termed, perhaps not entirely correct, proto-Etruscan. It was examined and described with exceeding care by Count Gozzadini, who made it known the following year, and who has since then made numerous other discoveries. The nature of the objects found in that cemetry showed that it belonged to a time posterior to the last period of bronze, but anterior to the Etruscans, with whom its dead had till then been confounded. It was after the discoveries of Villanova that *the first iron age* was assigned a place in science; this age had followed the period of transition from bronze to iron, corresponding to the upper layer of the palafittes, and had perhaps immediately preceded the Etruscan period, which extended down to historical times. Thus the past and present of man seem to be connected by a series of links, so to speak. Archœology is properly a branch of history, and is probably the most substantial part, as it is founded on real facts and not on mere reports often altered and sometimes falsified. Its commencement is connected with prehistoric studies, as the three prehistoric ages are connected two by two in their order of succession. In ascending from age to age, you arrive at the period of unpolished stone; beyond that there is probably a long term of years ending with a man of the quaternary, may be of the tertiary period; that is to to say, with the geological epochs prior to the one in which we live.

It is at this stage of science that theories begin, as those of Darwin on the origin of the human species, and its animal forms which have preceded and followed it.

In 1857, M. Troyon, in publishing the discoveries of Keller, called attention to the problem regarding the origin of bronze; but to solve it, it was necessary that a science as yet of recent date should be further developed by new facts, and throughout many countries. After Switzerland Savoy and Italy made the largest contributions to the study. Professor Desor the following year sounded the waters in lake Neufchatel, and after M. Morlot had, in 1860, published in Switzerland the discoveries made in Denmark and Sweden, a spirit of searching was manifested throughout the central countries. Messrs. Fastaldi and Desor that same year visited the lakes of Lombardy and found in the tour bières of the major lake objects similar to those in the lakes of Sweden. In lake Varesa, in 1863, Messrs. de Mortillet, Desor and Stopani recognized the period of transition from the age of stone to that of bronze. The palafittes were noticed only in later years around the fortress of Peschiera.

Since 1862, Messrs. Strobel and Pigorini have found not far from Parma, deposits of loam, known to husbandmen as *terramares*, and therein detected the remains of the old lacustrial habitations; in fact the stakes still remained, and were surrounded by organic matter; from the appearance of the alluvium it was evident that water had remained in the low portions of Emile, and that formerly there had flourished a civilization identical to those of the Swiss lakes.

We cannot here cite the names of all those who, since 1860, have contributed to the advancement of prehistoric studies, their number has increased in proportion as the increasing interest of research extended, and a method of procedure was adopted.

Suffice it to say that searches were made throughout Europe, and that the desire to contribute to the progress of the science of man, has called forth many exploring savants throughout western Europe. In Austria, there were Ramsauer and de Sasken; in Hungary, Romer; in Ireland, Wild; in Russia, Aspelm and Bogdanof; in England, Evans, Franks, J. Lubbock. In France, we have already mentioned M. de Mortillet who is at the head; to this name we must add those of Messrs A. Bertrand, Costa de Beaurregard, Cazalio de Fonduce, l'Abbe' Bourgeons, and M. Chantre from which we have derived much of our information.

In 1862, Napoleon III founded the Museum of St. Germain, which was established for the purpose of collecting the Gallo-Roman antiquities; the history of the Cæsars, in connection therewith, became a study of especial interest to the Emperor. The director was not slow in enlarging his plan and obtaining more help, and was soon able to offer to the public a prehistoric museum which well compared with the one at Copenhagen. It is to be regretted that a collection of this kind is 20 kilometers distant from Paris, which makes it inconvenient for the public; and the scientists do not derive the benefit they ought, so that it is not frequented very much.

Two years following M. De Mortillet commenced the publication of his "Materiaux pour servir a l'histoire de l'homme," a work of great interest which, in 1869, passed into the hands of M. de Cartaihœ. Since 1865, on the suggestion of M. de Mortillet, there was started an ethnological congress which is composed of the savants of Europe; this congress changes its place of meeting from time to time, and has already assembled, besides at Spezzia where it originated, at Neufchatel, Norwich, Copenhagen, Bologne, Brussels, Stockholm and Pesth; they propose holding their next sessions at Athens, Smyrna or Constantinople.

The impetus given to the prehistoric studies by these three French institutions, was increased by the universal Exposition of 1867, where a number of the products of primitive industry was gathered together. The Exhibition of 1878 will be still more important as it is intended to bring together entire collections from all countries. Germany alone will not be represented.

The number of books and memoirs relative to the ancient ages and particularly to the bronze age, is considerable.

There are very many public and private libraries throughout Europe, so that it is next to impossible for one man to visit them without devoting much time and money. The need of statistics, as full as possible to give all the learning available to aid in future discoveries, was felt. The demand was supplied by M. E. Chantre's admirable work entitled the *Bronze Age*. In one of the three volumes of which it is composed, there are only tables in which are classed in methodic order, all the objects of the bronze age found in France and Switzerland with indications of their orgin and where they can be seen to-day; there are at present almost 33,000 specimens. The other volumes contain much information of the other parts of Europe from which objects of bronze were gathered. If a work similar to that of M. Chantre was devoted to each of them, it might be easily believed that the conclusions of this savant would be confirmed, as they are founded on a thorough knowledge of all European collections, although his original intention was to have merely given statistics. As no work of this kind had yet been published on the prehistoric ages, it is to be expected that this one will form an epoch in the science and will be a starting point for new discoveries to begin.

III.

We will now speak of the places where products of bronze industry were found. The first steps of science were difficult and uncertain, because discoveries were made by mere chance, and by inexperienced men, who very often sold their antiquities by the weight, and sometimes destroyed them even. Thus in 1859 on a farm of M. de Gourgue near Bordeaux, "the husbandmen on returning from the fields, told their master that during the day they had found a corpse, that they tried to smash its head with their sabots, but it was so big and hard that they could succeed only with their spades." They brought back with them however, a hatchet, a sword, golden threads and fragments of pottery. The following occurred in 1865 at the celebrated prehistoric foundry of Larnaud (Jura), "Brenot fils, while digging potatoes, discovered a piece of green metal which excited his curiosity and that of his friends. They set to work and found a quantity of objects of the same metal within a plot one meter square. The next day Brenot père took a specimen to Lons-le-Saulnier, a brazier, who told him that the bronze was worth forty cents a kilogramme. On this man's suggestion, Brenot offered his treasure trove to an amateur of antiquities, M. Z. Robert, who did not hesitate to take them. There were about eighteen hundred pieces, weighing 66½ kilogrammes." All this bronze came near being thrown into the crucible of the founder. It is now in the museum St. Germain, and is one of the most interesting collections. One more incident may be given. The ancient foundry of Vernaison (Rhone) was found in 1856 on the property of M. D——. The total weight of the bronze was 16 kilogrammes, but the director of the Lyons Museum at that time, retained only a small portion. "We have selected," said he, "the complete, or mutilated objects most worthy, to adorn the museum, the rest was returned to M. D.—, who proposes to have cast a commemorative urn, with an inscription recalling the event of the discovery." Notwithstanding the dangers by which the prehistoric science was surrounded, the bronzes in France and Savoy are already so numerous and so well characterized, that M. E. Chantre has been able to class them into categories which we divide in two groups; the *visible strata*, and the *hidden strata*. The first comprises grottoes, dolmens and palafittes or lacustrial habitations; the second, treasures, foundries, isolated stations and tombs in open fields.

It is well known that caves formed the first habitations of man, not only during the stone, but also the bronze age. Throughout Europe inhabited caves are found. The most interesting perhaps, are those of Central France and on the banks of the Meuse. The latter have the advantage of being in three planes, representing three successive risings of the river which irrigated its banks. They present supposed layers of human remains of three consecutive epochs; that of metal, of polished stone, and of rough stone. The latter which is beneath the other two, is no longer found on a level with the other two layers which were then beneath the

water, for the Meuse at Dinant was not less than three leagues wide. Among the human remains there are bones of mammoths, hyenas, rein-deer, animals which were then in France and Belgium. The inhabitants of the caves made earthen vases, but knew not the art of baking them, although they had fires. M. Dupont, (L'homme pendant l'age de la pierre) from whom the following is obtained, estimates that during the period of the mammoths, the width of the Meuse at Dinant decreased from 12 kilometers to 400 meters, which is the distance of the caves in the center. To-day it is but thirty meters. The middle layers just beneath those of the mammoth, correspond to the period of the rein-deer, the grottoes, which are termed pits of the Mitons, of Chaleaux, of Frontal, are striking examples. The remains of human industry are buried beneath a bed of yellow clay which covers them. In these no bones of mammoths or hyenas are found, but only those of some species now living; the wolf, fox, deer, wild goat and rein deer. There are not yet any polished stones; there is no trace of metals; the potteries are made by hand but are not baked; small stones, pieces of bone, teeth of animals, or fossil shells with holes, composed the ornaments of those people. The third layer, corresponding to the inferior caverns on the borders of the Meuse, is that of polished stone; it is the epoch of dolmens and lacustrial cities of Switzerland, Savoy and Italy. Yellow clay disappears, the rein-deer, elk, wild bull, and castor have all disappeared. The hatchets are made of polished stones with holes for inserting handles; the potteries are now baked. This epoch has left behind but little remains in caverns, but much is found in the earth of the fields. It is here that bronze makes its first appearance, and though scarce in Belgium, is found in great quantities in Central Countries. The caves of the bronze age in France and Savoy are of two kinds, those used as dwellings and those, whether natural or artificial, for sepulchral purposes. As on the Meuse, the inhabited pits of the middle states are found along rivers, and belong generally to the period of transition from polished stone to bronze. They are scarce, and among the most important are those of Saint Saturnin, a large neolithic station above Chambery, those of Savigny near Albano, of la Salette, and of Louvaresse (Iseria). The people of the neolithic period who witnessed the arrival of bronze inhabited the plains, and often the borders of rivers. The banks of the Saone furnish us with many stations, of which the successive epochs appear in superposed layers; it is especially at the confluence of streams and about fords that they may be perceived.

Where the waters were tranquil, and produced but few changes, that is to say, near the lakes, the men of that period no longer used caves. They deserted terra firma and built houses above water, resting on piles. None are seen on the steep banks of lakes as the water is there too deep, but they are found on shallow banks of sand or earth where the water is not profound, as in fords of rivers. What could have induced those men to isolate themselves in the middle of these lakes? We have not yet learned, but it is to be hoped that new observations will solve the problem. However it may be, we perceive that this custom lasted a long while, as the palafittes of the Alps comprise not only the epoch of bronze, but those which had preceded it, and those also which mark the arrival of iron. There are palafittes of the stone age at the lake of Zurich, of the bronze age at Limau, of the iron age at Neufchatel, and each of these periods is well characterized. There are certain lacustrial habitations belonging to the two periods of transition which mark the beginning and end of the bronze age, so that it is at least certain that the custom of living over water, continued without interruption for a long time.

As there were found habitations built on piles in the north and center of Italy, it would be interesting to explore the lakes of Central Europe, of Greece and Asia minor, and determine how far the custom extended.

The men of the stone age consecrated natural grottoes for burial purposes, while they also made use of caves as dwellings. Thus on the Meuse, the small cave of Frontal was used as a cemetry for the men who dwelt in the cave of the Noutons. This mode of living was still existing at the appearance of bronze.

This is proved by the "Grotte des Morts" near Sauve (Gard). Since 1795 d'Hombre Firmas had called the attention of geologists to this cave, but it was examined only in 1869. M. Tessier died during the first clearing out, which was afterwards accomplished in the name of the Scientific Society of Alais by Messrs. Cazalis de Fondouce and Ollier de Marichard. The cave is a sort of vertical well dug out by nature in a crevice of inferior lias. From this there have been dug a large number of bones of men, foxes, wolves, wild boars, horses, sheep, a complete funeral accoutrement, composed of arms and tools of silex, bom, or deer's horn; a quantity of jet jewelry or of black or green marble, spath and Alabaster, an awl of bronze and many iron pearls, many of which were left behind with the rubbish. We will also mention among the natural caves of the first bronze period those of Labry and Baniere (Jard) which have brought to light objects similar to those already found, besides a poignard, ear-rings and bracelets of bronze, and the caves of Gonfaron and Chateau double (Var). That of Saint Jean d'Alcas (Aveyron) discovered in 1838, was searched in 1865 by M. Gazalio. It is partly artificial. At the entrance there had been placed two large arched stones supporting the roof and forming a triangular entrance. One unfortunately has been taken away by the owner of the cave, and used as a door-step to his kiln. Among the numerous objects thrown out with the dirt by the same person, there have been picked, mingled with bones and silex, two hatchets of polished stone, pearls, a spiral and bronze ring.

The artificial sepulchral grottoes have received the name of covered alleys (alées convertes). They are especially found in Provence, dug out of the small calcarlous masonry-works which appear as islets in the fertile plains of Arles. They consist of an oval gallery open above; the walls are inclined towards each other; the top being covered with large flat stones which must, in the first place, have been covered with earth. One of them, the Grotto of Cordes, which is also called the grotto of fairies was in turn supposed to be a Gallo-Roman cave, a Saracen prison, a Druidic monument, and, lastly, a sepulchral Grotto of Asiatic or Phœnician origin. "You first of all descend" says Mr. Cazalis, "on large rough stairs into a fore court, uncovered at present, which is in the shape of a sword; from thence you proceed, through a gallery six meters long, into the cave proper. At the mouth it is 3.80 meters wide but narrows in the rear; the walls are sloping. This trench, which is twenty-four metres long, is covered by inclined stones and the whole covered by a tumulus which is much worn. The total length is not less than 54 meters." Unfortunately, the funeral outfits of this cave were scattered, so that the epoch cannot be determined, except by its resemblance to the Grotto of Castelet in the neighborhood. The latter contained sixty centimeters (2.6634 inches) of earth and gravel, brought, to all appearances, from Gardon. On this lay the bones of about ten men, together with instruments of silex and bronze, and a saucer of pottery made by hand. For a long time *Dolmens* were looked upon as Druidic altars, a vague term which with the words "Celtic" and "Gallo-Roman" is indiscriminately used. Since they have been found, not only in Western Europe, but throughout the whole Continent, Africa and Asia, new theories have been current. Some scientists have looked upon them as spontaneous transformations from caves; others thought they recognized, from their distribution over the old Continent, the migrations of a wandering tribe, which, driven from Central Asia, would have followed the Baltic, stopping in Scandinavia, and which would then, driven from the Northern countries, England and Ireland, arrive in Gaul, then proceed to Portugal, and finally to Africa. We do not suppose that dolmens have as yet been the subject of sufficient observation in Africa and throughout Asia, nor even in the different parts of Europe, that any theory should already be substantiated.

The monuments which have received the appellation of megalithic, nearly all belong to the period of polished stone; still a large number date from the appearance of bronze. Those of the North are generally the oldest; and if we may judge of their relative dates by the quantity and quality of bronze which has been obtained, their antiquity

diminishes in proportion as you descend from North to South. This does not prove however, that dolmens originated with a race descended from the Northern countries; it would on the contrary indicate that bronze brought from the Mediterranean countries, reached the North only by slow degrees. There are 147 dolmens in the South of France in which bronze has been found: they are mostly situated in the region of Cevennes, a short distance from the Mediterranean. Several dolmens from Marne and the environs of Neufchatel have also yielded some. Those of Bretagne, with the exception of a few in which a little metal was found, belong to the neolithic period. The 147 dolmens in which bronze was found mingled with objects of stone, pottery of the second period and other objects which will be mentioned further on, form but a minority of the great number which have been explored. In the South of France alone, 700 have been opened in Ardèche, 300 in Aveyron, 160 in Lozere. It may be taken for granted, that if all belong to the period of polished stone, the people who built them witnessed the arrival, in small quantities perhaps, of the first common metal. If they had had it in abundance, they would in all probability have made arms, instruments and even ornaments of bronze instead of stone, shell, horn, or bone, for with a silicious saw they could accomplish in one day of hard labor, what with a bronze saw they could do in an hour, with an iron saw in a few minutes, and in a few seconds with a steel saw impelled by mechanical force. Let us suppose it is yet the custom to bury with a person the objects he has used during his life time, and that in five or six thousand years our graves should be opened, many circular saws would be found in England, France, Switzerland, Germany, but few in Italy, especially towards the South, still fewer in Spain, one or two in Greece, and not one perhaps throughout European and Asiatic Turkey. We do not, however, notice any migrations in our midst; the industries themselves are propagated, but the people do not migrate; a few men passing from one country to another suffice to introduce new industries. The composition of dolmens is uniform, only that bronze increases from North to South; it seems then that there existed in the Mediterranean regions, or beyond, a country from which bronze is brought and distributed through the Northwest of Europe.

We must now speak, from the numerous facts collected and classed by M. Chantre, of the beds of bronze which were hidden under ground, and brought to light by mere chance. They are of two kinds; the *foundries* and the *trésors*, to which may be added certain stations or centers of habitation as yet not well classified, and a number of tombs in open fields, whose presence there is nothing to indicate. A foundry consists ordinarily of a mere cavity dug out of the earth, and contains more or less complete the materials of a bronze-founder; ingots of metal, refuse and waste metal, ashes, fragments of things of little value or worn out, or defective, and, finally, crucibles, moulds, pincers, and sometimes even new objects coming out of the moulds and incomplete. Many of such foundries have been discovered in parts of Europe, especially in France, Savoy and Germany. Should the place and statistics of each be desired, I would refer the reader to the book above cited. The foundry of Larnaud may serve as a specimen. I have already stated how the son of Brenot the farmer, discovered it in 1865, and how, when offered by his father to a brazier of Lons-le-Saulnier it was saved by M. Zephirin Robert. After having been exhibited during the Exposition of 1867, in a store on the Boulevard des Filles du Calvaire, it was bought for the Museum of Saint-Germain. The case in which it is exhibited has been classified and labeled by M. Chantre who, in his work, gives a catalogue and full description. The value of the collection obtained from Larnaud, consists in this, that all the pieces which compose it are contemporaneous: there are 1485 such pieces, and the epoch to which they belong is evidently the end of the bronze age. This is what is shown by a comparison with those of the other foundries, and especially with the objects obtained from the palafittes of Savoy. Throughout, the last epoch of bronze is characterized by traces of the hammer, by the presence of metallic plates or leaves obtained by concussion and not merely by casting. On the other hand,

that which links the workshop of Larnaud with the age when bronze was the only common metal are the cold chisels made of hard bronze to cut bronze, as steel cuts iron. But since bronze is softer than iron, can it be doubted that cold chisels would have been made of iron, if the latter metal had been known or was at least abundant? We will give further proofs showing more clearly the epoch to which we must refer the foundry of Larnaud.

There are other foundries belonging to this period, among which we will mention that of Poype, situated on the heights overlooking the Rhone to the South of Vienna. A portion of the bronze had been sold to a merchant of Lyons, at the price of old brass; it was bought by M. Chantre who, on precise indications, renewed the search and was able to duplicate the products. The foundry of Goncelin is also situated on the heights adjoining the Iser, as well as those of Thoduse and Bressieuse. The largest portion of the other stations of this kind are in the neighborhood of rivers, and probably at a short distance from the places then inhabited. What is probably the most remarkable is their uniformity throughout Europe. They indicate, to all appearances, the passage or stay, long or short, of workmen belonging to the same class, but who were not natives. Foundries are, in fact, always found in isolated spots, but no traces of human habitations are seen. It is true that habitations may disappear, wooden houses crumble into dust, and the very stones become, in the course of time, dispersed and used elsewhere. There is, at any rate, one product of human industry which never disappears, and attests the presence of man during the most ancient times; that is the baked clay and especially broken pottery. Its tenacity is such, that on closely comparing the soil with some of the fragments, it is often easy to determine the place and size of cities which have disappeared several centuries ago. The neolithic foundries are never surrounded by such ruins.

There are but few lacustrial habitations where the metals were wrought, but here the natives might have been taught by travelers. The initiation seems, in fact, probable, from the existence of certain inhabited spots, which are called *stations*. Those which are known are not very extensive; in most cases they are on a line with rivers, as may be seen, for example, on the banks of the Saone between Chalons and Tournus; still there are some isolated ones. The most important of them all is that of Saint-Pierre-en-Chastre in the forest of Compiégne. It is situated on the calcareous plateau in the swampy plains of Vieux-Moulin. It was dug by M. Viollet-le-Duc in 1860, and yielded, among other things, more than five hundred bronzes, which are indistinctly attributed to Gaelic armies. Since then, science having made some progress, they have found that it is necessary to distinguish the objects of stone, bronze, or iron obtained in that locality; that all was anterior to the time of Caesar; that there were few arms; that the quality of bronze was identical to that of the other layers of that age throughout Europe. On close examination, comparisons showed that the station of Saint-Pierre had probably existed for several centuries, and that it had witnessed if not the first appearance of bronze in that country, at least the epoch of that metal, and the commencement of the iron age.

But the interest in the stations is, in part, lost in that of the *trésors*, as these seem to demonstrate the reality of the traveling founders; the idea merely being suggested by the foundries. The most important were found in the Alps on the neck of the mountains, some near Moulins and Gannat, two in Meusth, and one near Sarrelouis; there are altogether twenty-nine in France, comprising upwards of 1350 pieces.

These treasures are composed of new objects, never having been used; sometimes several are joined together having been cast in the same mould.

They are found in small cavities expressly dug, where they seem to have been hidden for a short time by their possessors. These treasures, those of the Alps at least, are often found on high ground, not far from roads, frequented by travelers going from one country to another. There are no signs of a foundry in the vicinity, or even of a station, the spots where they were found are deserts. Is there anything to be found in these temporary deposits

besides objects of traffic? Were they not hidden by the same men who, in the valleys, recast the inferior products of their own industry? If all this leads us to believe that such is the origin of the treasures, there would only have to be determined the direction in which these workmen went, to know whether they came from Italy to France, or vice-versa. It will directly be seen that this difficult problem is no longer insoluble to-day.

The treasure of Reallon, which is now in the museum of Saint Germain, was found in that village not far from Embrun 3880 meters high. "This road, anciently frequented by foot-travelers, leads from Saint Bonnet to Embrun, by Gociere." The treasure of Beauviĕars was found by a farmer. This village of the arrondissement of Die is situated on an ancient passage of the mountains, on the peak of Calre, on the road to Luc. There were many other valuables which had been stowed away on the upper banks of rivers, as well as on the plains.

IV.

We must now speak of the industries of the bronze age of which the several strata compared with each other have revealed the existence, nature, processes and relative epochs; among them there were some indigenous. Undoubtedly the men of those ancient times must have built their own houses, which were made of wood, after the time they left the caves. Those they erected on solid ground have disappeared without leaving any traces behind; and if the houses of the lakes have been destroyed, at least the piles upon which they were built still remain. Those of the epochs anterior to metal, were nearer the banks and did not project so far out of the water. The others were built beyond the first, and in Savoy, have a greater jutting out, by which they can easily be recognized. The pieces of wood resting on the piles and forming the flooring, were fastened together by means of tenons and mortises; which shows clearly that they could with hatchets and chisels of stone, cut and shape large pieces of wood. Planks were made by splitting the trunks of trees; the stone saws are only several inches long, while those of bronze are not a foot; they could only be used on light work. Of these several specimens have been extracted from the lakes of Savoy, such as spoons, tool handles, spindle shanks, sabots, a porringer, and part of a bucket.

The great number of bobbins of baked clay which are called by the Italians *fusaioles*, indicate that the custom of spinning and weaving was then extant; there were many discussions as to the use of those small cones bored through their *axis*, but there is now no more doubt, since a complete spindle was found in the lake of Bourget. We have ourselves seen pieces of wood worn out in the holes of many bobbins, found in Troy by Dr. Schleimann.

These very things are still used throughout the Middle and West of Europe. They could obtain very delicate threads with these spindles of wood and clay, as is evident from the smallness of the eye of several bronze needles. The finest textures have been destroyed under water as well as under ground, but a few specimens of the coarser textures, meshes of nets, thread, cord, and bundles of beaten flax, have been preserved in the mud of the palafittes of Bourget. The flax then used had small leaves, and differed from the kind now cultivated. To the weaving we may add the fabrication of baskets of rushes, reeds and osier, and the making of fishermen's snares, and the large hurdles which were used to fortify the walls of houses in supporting the roof.

The local industry which has left the most traces in the strata of bronze, except the treasures and foundries, is the moulding of argil. We have already noticed that the potteries of the periods of stone were not baked, but merely dried in the sun. The art of baking was introduced during the age of polished stone, and continued to be improved during the entire age of bronze. Still the most ancient vases of that period were badly baked, very often burnt on one side and raw on the other; it would seem that these potteries were cooked in the open fire and not under a reverberated furnace, which however was the case. The dishes and plates showed few signs of the fire. It was only towards the end of the bronze age when iron was already beginning to supplant it, that the potter's wheel was used. As simple as was this revolving machine, it afforded

certain facilities of fabrication which were formerly unknown. The progress seems to have been made only after the appearance of iron. The various kinds of vases fabricated by processes so elementary were astonishing. Some were used for carrying water, others for preserving and cooking food. There were also some drinking vases, among which are the rhytons, and lamps in imitation of the old Greek and Roman lamps, rings of clay used as rests for small-cased vases and peforated cheese molds as in our own day, which shows that men in olden times were fond of the product of the dairy.

With regard to the ornamentation of pottery, it has received special attention from scientists, for it has afforded, during the bronze age, transformations useful in chronology, which are found on contemporaneous bronzes. The rough pottery of the stone age was ornamented by straight lines engraved thereon with zig-zags more or less irregular. In course of time these lines became more regular, and are drawn parallel by means of burins with several points, consequently the figures are more accurately made. The use of concentric rings may be noticed throughout Europe during the bronze epochs. The plain cross, the multiple and four pointed cross, the encircled cross in shape of a wheel, stars and triangles appear regularly in successive years.

The figures are no longer merely engraved with pointed instruments, they are also impressed with stamps of metal, clay, or stone. The Swastika (a species of cross with curved arms) and the meandre which is made up of a succession of swastikas, are to be met with especially during the period of transition from bronze to iron. During the first iron age, and further on in historic times, this figure was popular with the people of the Aryan race, and appeared in the west after the bronze ear. It was about this time that the potters began to paint certain vases with red or yellow ochre or with that black which afterwards became peculiar to Grecian ceramics. Lastly, the inhabitants of the lacustrial dwellings used a sort of decoration which was, however, afterwards abandoned. On the dark bottom of some vases of fine clay, they fastened thin sheets of pewter cut in narrow strips, with rosin, and formed a variety of beautiful designs. Metallic ornamentation, no doubt, had its origin in the West. The industry of bronze characterizes the period now under consideration. In speaking of the foundries we made little mention of the material of the founders; so far there has been found but a small piece of mineral brass, and nowhere in Europe has a furnace or any instrument for extracting ore been found. We may, therefore, be justified in supposing that the metal was brought from the vicinity in its rough state, or already molded. In fact, ingots of bronze are found wherever the founders were stationed, they are in the form of small squares, or like hammers having a hole in the center to hang them up by.

We should recollect that no pure copper* is found, very little tin, whilst throughout Europe bronze is of uniform composition. The following is obtained from the analysis made by Messrs. Wibel and Fellenberg and by M. Damour; the proportion of tin is about ten per cent., but there are exceptions as in cold chisels and one or two other objects of hard bronze, which contain as much as a quarter of tin to three quarters copper. This uniformity of composition of alloy throughout Europe, proves the unity of its origin and importation, but of this further on.

Researches have brought to light besides ingots and refuse castings of metal, a number of molds made of schist, steasheist, free-stone, baked clay and bronze. Many of these have figures on two or four sides, and on some there are several figures along side of each other. The crucibles are made of earth mixed with broken quartz and often contain metal. Some have the shape of the laboratory crucible, while others are like cups with handles. All these receptacles could contain but a small quantity of metal; their form and dimensions are pretty much the same throughout Europe.

The articles, made by means so rudimentary, may be divided into three classes, viz., tools and utensils, arms and ornaments. Among the first may be included the hatchets first made similar to stone hatchets, with holes for the pur-

* It appears that in Hungary and Greece many specimens have been noted.

pose of inserting a handle which was fastened in the socket with a cord. We are able, considering the superposition of the layers in the lacustrial habitations and stations to follow these transformations, and determine their relative epochs. Scissors, knives, chisels, sickles, handles, saws, gimlets, jewelers' pincers, are the tools usually found in all the strata. We may also add razors which were first made of hard stone, then of bronze, which are finally supplanted by iron ones. These instruments were not of the same shape as they are to-day; they were semi-circular with the edge on the side of the curve. Then there were some double ones edged on both sides of their diameter, and fastened to an ornamented handle, forming together but one piece. The different razors will enable us to ascertain the relative age of the strata in which they are found.

Was the horse domesticated at the appearance of bronze? It is probable that he was tamed during the period of polished stone, and yet it is possible he may have been long before. If he was then only in a wild state, it would be difficult to explain the quantity of bones which are found in certain places of the first period of stone as in Polutré. This station which is not far from the Saone river, above Macon, contains, it is said, the skeletons of 100,000 horses, most of them young, which may have served as food for the inhabitants of the place.

Be it as it may, the bronze bits found among the piles of the lake of Briene and afterwards in France, bear witness to the fact that the horse was already subdued. The oldest of these bits are made of two moveable pieces one above the other in the center of the animal's mouth. Soon after the four pieces are movable, although each of the exterior pieces has a cross-piece through the middle, and thus forming two equal branches. This second class of bit characterize the terramares, and had been learnedly studied by Count Gozzadina. It seems that in the stone age the horse half tamed was used as food for man, that being subdued in the second period he was mounted and perhaps harnessed, and, finally, at least in Italy at the end of the bronze age he became tame enough to be guided about with a string. Arms do not form the least interesting portion of our bronze collection; they perhaps better than anything else enable us to determine the successive phases of this metal. They are found everywhere in Europe and Asia, but they should not be attributed to Gaul as has been done. The palafittes, foundries and treasures have given them their definitive place in the bronze age, and if they appear only in small quantities owing to the scarcity of the metal, they soon become so abundant as to supplant entirely the arms of stone. Later on iron is found in many places in Europe, but in small quantities and is regarded as an object of luxury. It soon after exercises in its turn an appreciable influence on bronze arms, the form and size of which are modified. Finally, bronze is entirely abandoned. The blade of the swords and poignards of the early part of the bronze age was of metal, but not the handles. Often in these primitive arms, the tongue of the blade does not go far into the handle; it is broad short and piereed with two or more holes through which the iron rivets pass. Afterwards metal handles are made, either without a guard or one in the shape of a cross. Switzerland, Denmark and Sweden have produced swords with antennæ, that is to say, with two prongs jutting out and curved at the end of the handle above the hand. The long swords, the length of which is often two feet and a half, which are to be found throughout the West, had handles made of horn, wood and bone, and resembled the iron sword which soon replaced them. In France there have been discovered 650 swords and poignards of bronze, in Switzerland 86; in Sweden 480, and are generally found throughout Europe.

The dolmens and sepulchral caves of Lauguedoc and Vivarais, the palafittes of the lakes of Neufchatel and Varesa, have produced arrow heads similar to those of silex which had preceded them, and used up to the transition from stone to metal; they characterize this epoch as the razor characterize the transition of bronze to iron. These small pieces of metal were flat, being fastened in the shaft with a cord.

It is during the second period of the bronze age that armor is made of metal, as helmets, shields and cuirasses; prior to this time they are made of leather and wood. This is the period

that M. de Mortillet designated by the term "Chandronnerie," the art of enlarging and shaping iron under the hammer, being added to that of molding. This method was used not only in the manufacture of armory, but also to the edging of arms and tools and of a multitude of ornamental objects.

The latter outnumbered the former, especially when metal was rare; pins are picked up by hundreds. The foundry of Larnaud has furnished 214 bracelets, the lake of Bourget more than 600, and a great number have been found in the dolmens of Central Europe. The oldest are oval, the latest are round; those which date from the bronze epoch are open, but are closed as soon as the industry of iron is general. The large collar rings, called torques by the Romans, is not found until after the appearance of the latter metal; finger rings are scarce throughout Europe, but plain rings, necklaces and buckles, are everywhere found in large quantities; there are besides these many other ornaments or amulets, such as ear-rings, fillets, &c., which evidently have a symbolic character. Let us here note that these symbolic figures are about the only signs of any religion during the bronze epoch. We may add that they are not indigenous, but are doubtless derived from Asia, as also the cithern which is made of hollow reeds with nine or twelve rings fastened at the end of a stalk of wood. There are several in existence, two of which were found in France, three in the lake of Bourget, the others at Christiana, at Wladimir and Yavorlan. These citherns are not like those of Egypt, but like those of the priests of Buddha, who themselves hold them of an ancient Aryan tradition.

V.

We have just placed before our readers the general conditions of the problem relative to the origin of metallurgy in Europe.

From the facts which have been briefly stated, but may be found enumerated and more fully described in M. Chanter's great work, and especially after seeing the objects themselves in our museums, they will satisfy themselves that the problem is henceforth well sustained, that the method of proceeding is determined, that the researches of primitive bronze and the scrupulous examinations of the strata in which it is found are the principal if not the only means to arrive at a solution, and that finally the accumulated works of many learned men throughout Europe have already given to science a large and solid foundation. This immense work which we have condensed in a few pages was begun about forty years ago, but has been generally known only within the last twenty years.

Europe has not yet exhausted itself, still we feel that the origin of metallurgy must be sought for outside of its frontiers. When warriors will give a little respite to science, the East of Europe and Asia will become the scene of scientific discoveries; in fact, the first appearance of the metals must be sought for in the Southeastern portion of Asia. Still to be certain of the fact, we should, by investigations analogous to those made in Europe for the last twenty years, to a certain extent trace the routes which the industry and commerce of the metals have pursued. These routes, at least with regard to bronze, will converge no doubt towards one point. If Central India and Tartary had simultaneously furnished this metal, we would see in all the collections of Europe two different types and, probably, two different alloys in objects of the same kind; but the converse is true. Except the local differences arising in different ages, the products are the same throughout the West, from Sicily to the Northernmost of Sweden and Russia. The composition of bronze obtained from a number of analyses in which the approximation was to a ten-thousandth part, is the same everywhere; the scientific processes are identical. The three successive epochs of the bronze age is everywhere perceived; first, wherein it is seldom found amid a people occupied in polishing stone; second, wherein metal has definitively replaced the latter in certain usages when decidedly superior, and lastly, wherein bronze concurs with a new metal, iron, which eventually supplants it. Such a uniformity at a time when there were no roads and no protection, when the races which inhabited Europe had not yet mingled and experienced their respective wants, and

had their own special trades; in fine, the absence of tin in Europe except in Cornouailles, as well as native copper, are sufficient reasons to lead us to believe in the foreign origin of metallurgy.

To arrive at a starting point we could at present proceed by elimination and show that neither Northern Asia, Caucasia, Tartary nor Egypt could furnish bronze to ancient Europe. In narrowing the circle we would be led, as many scientists have been, to look upon Asia Minor as the country through which bronze was carried, and India as the place of its origin. But India itself is large; from Cape Comorin to the Himalayas the distance is about that from Marseilles to Petersburg. Moreover, India does not produce its own bronze, it imports it. This method, however, which is not very scientific, and which has led many men astray, merits some consideration; bronze, which is a composition difficult to produce, must have originated in a country where the elements are to be found; India does not produce tin. We should regard the peninsula of Malacca and Banca, which are even to-day the two great centers for the production of this metal, as the birth-place of bronze; these facts then are the result of the system of elimination. We do not mean to say one would be led into error, but at most would only propound a probable hypothesis. The learned scientists have attempted to solve the problem by reference to texts; unfortunately the most ancient texts are of recent date, considering epochs of such antiquity. Moreover the authors of these texts, whose individuality is a matter of doubt, were not well informed, since none of them had any idea of the three successive ages of humanity. In vain did M. de Rougemont, in 1863, with only the aid of texts, pretend to have solved in his cabinet the problem, for a solution of which scientists have sounded lakes, turned over the sods of the field, and dug into the mountains. This learned man, for whom the book of Genesis was a sufficient authority in metallurgy, designates Phoenicia as the country from whence European bronze was obtained. But there are not mines either of tin or copper in Phoenicia; the nearest copper was to be had in the isle of Cyprus which after all was not Phoenician; besides, these were never producers, but only merchants. It would be impossible to show any Phoenician bronze anterior to iron. We will here add that the emblematical figures of Europe are foreign to Phoenicia, and that the author of the fourth chapter of Genesis had but vague notions regarding the origin of metals. There is then no other method to follow but the observation and comparison of facts. If the facts just enumerated prove the foreign and unique origin of bronze industry, the local differences are liable to three divisions in Europe; the Ural, Danubian and Mediterranean, and these may be subdivided into provinces. In noting the successive epochs indicated by the superposition of the layers of the palafittes and stations, we can determine the relative state of this industry in the different provinces of each group with each of the three epochs of the bronze age. The nature of the objects associated in the layers show the successive phases through which this industry passed. Now the first bronzes sold in exchange for amber, furs, leather and other products, to the polishers of stone, were bijoux and amulets. We are able, by comparison, to follow the march of the commerce of jewelry from country to country in each province. We next find utensils and arms, and, lastly, appears the era of metal beating, that is, the hammering of bronze, following the simple fusion, and thereby undergoing a complete change.

These three series of observations, founded on the thousand objects in the public and private libraries, have shown that if the Ural group which borders on Asia is set aside, the provinces of the Danubian group received bronze from regions near or below the Danube, while Savoy, France and a part of Switzerland received theirs from Italy across the Alps. The waters of the Danube spread as far as the lakes of Eastern Switzerland, and it is to this river we are indebted for the bronze objects found in the palafittes of Zurich, while those of Savoy were borne by Italian waters. The bronze works of Germany, Denmark and Sweden, and, to a certain extent, those of England and Ireland belong to the Danubian Industry.

The Italian industry fills the basin of

the Rhone, and extended on one side as far as Savoy, on the other to Cevennes, then proceeded to the North of France, its influence being felt as far as Great Britain.

Now how was this propagation of metallurgy effected? The foundries and treasures answer the question, imperfectly however. The earliest disclose foreign workmen who established their workshop in open fields, not in populated cities, but in their vicinity. Not having any permanent homes, they wandered from place to place and would here and there melt old articles and mould new ones, any deficiencies being supplied from ingots or bars of bronze they carried about with them; their treasures much resembling the parcels and bundles of nomadic merchants. How can we account for the appearance of those found at the top of mountains where there are no habitations? But the findings indicate that these unfortunate men did not return and that they were a prey to violence or misery in other quarters. And why have these very foundries preserved the molds and crucibles, the ingots and broken objects which were to be recast? Why should these workmen have left these articles behind them? Or, rather, have they not been the victims of hatred or cupidity? Herodotus says, that there was in his time a sort of corporation or class composed of nomadic founders who came from Asia. During the whole of the middle ages, these strangers differing from the men of the West, frequented our cities and towns. Their nomadic mode of life, their unknown tongue, their strange customs and religion which seemed to be paganism, were the cause of their being hated and ridiculed, although their services were much needed. They were murdered without mercy. Modern industry has almost banished them from the most civilized countries; but they overrun the East, the Middle and North of Europe, without counting the whole of Asia; they come like the men of the bronze foundries, to remain a few days in the fields near the cities. They are known by different names in different countries; tsiganes in Hungary, zingari in Italy, bohemians in France, gyphtes or Egyptians in Greece, gypsies in England, and gitanas in Spain. They are not united together, but are members of a corporation dependant upon a chief. It is from this chief residing at Pesth that they receive the metal, and he himself receives it from another who lives at Temesvar, but whence does he obtain it? It is probable that the similarity of the events of the bronze age and the customs of modern pewterers, will enable the scientists to discover the course of ancient metallurgy. The route of commerce is not much changed in countries where the inventions of our day have not yet penetrated. The processes were perpetuated; in the East the same tribes furnished men in the same business. Now it is a fact that the tsiganes belong to India; we know from another source that there were no castes in the time of Veda, but there were then trades among which that of founder had important place. But are these founders of Aryan race? Did they belong to that part of the conquering nation which, in its march to the Southest had not yet reached the valley of the Ganges, nor gone beyond the Saraswâti? It is easily seen that problems arise and multiply, and how necessary it now is to pursue, outside of Pesth (the last place of the anthropological congress), the searching which has been going on in the West for the last quarter of a century.

The point of departure from the Italian current is not any better known. Discoveries have shown that the Rhodanian industry comes from Italy, and that Italy made more progress than the countries farther North; but the working of bronze is not any more original in Italy than it is in France or Savoy. From which side did the founders gain access to Italy? Did they come from Greece or from the islands? And when it will have been shown that they came from Greece and that Greece preceded Italy in civilization during the bronze epoch, it will be necessary to show from whence Greece received her bronze. Did she obtain it from Asia Minor, Cyprus or Egypt, or from some other country? From the moment we disregard the Adriatic, the problem is unsolved, as the countries beyond this sea have not yet been searched. The discoveries made at Santorin by M. Fouqué and the French school, and especially the great researches of Dr. Schliemann, at Troy, and Mycenæ, throw

a ray of light on our subject, but do not yet entirely solve our problem. And this will not be until new discoveries shall be made in many places in the Grecian peninsula, in the islands, and over the far-spreading surface of Asia.

In these countries there will needs be found the commercial equivalent given by the men of the West in exchange for bronze brought by the Eastern men. These objects of barter will be found to consist principally of yellow amber, a precious substance which remains intact in the earth as well as in the sepulchres. The comparative study of religion will furnish to science a helping hand, for we know that the symbolical figures of certain bronzes found in the west belong to the Aryan race and come from Central Asia or India, such are the swastika, the cross, the wheel, the crescent, the disc, the stars and numbers. These symbols, plainly characterized, will be like so many stakes in all places where they shall be found, and these stakes marked on the chart of the world, will indicate the metallurgic paths. Philology already gives us a little information, but perhaps we should not depend on it too much, for the names given to the metals by the Aryans of the West do not always have the same signification they do in the East; but, as in India for instance, the names designating the same metal, same industrial product, same figure are always numerous and significative, they will enable us by comparisons, which will complete or clear up those derived from science, and thus will the study of texts, which has been so abused, become useful. Be it as it may, scientists admit at present that the courses of metallurgy in Europe—that of the Danube and that of Italy and the Rhone start from the European continent and tend to converge towards a central point of Asia which has not, however, yet been determined, but they also admit that the epoch when bronze was introduced in Europe among the people of the neolithic period is yet at the state of the geological period, and cannot be included in any chronology. Will a real date ever be determined upon, or at least an approximate one? We doubt it, but at least hope so.

THE CO-EFFICIENT OF FRICTION FROM EXPERIMENTS ON RAILWAY BRAKES.*

By Captain DOUGLAS GALTON, C.B., F.R.S., D.C.L.

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The author of this paper has been recently engaged in making some experiments upon the co-efficient of friction when the surfaces in contact move at high velocities, in connection with the action of brakes in use on railways; and the results which have been arrived at appear to present some interesting features in respect of the laws which govern the co-efficient of friction.

These experiments form the first installment of a series which it is intended to make, to ascertain, 1st, the actual pressure which it is necessary to exert on the wheels of a train to produce a maximum retardation at different velocities; 2nd, the actual pressure exerted on the wheels in the several forms of continuous brakes now in use; 3rd, the time required to bring the brake-blocks into operation in different parts of a train in the several forms of continuous brakes; 4th, the retarding power of the different kinds of continuous brakes now in use on trains under similar conditions of equal weight and running at the same speed.

This paper includes the first series of experiments only.

The author was enabled to make this series through the courtesy of the London, Brighton, and South Coast Railway Company, and of their locomotive superintendent, Mr. Stroudley, who provided a van and other facilities for making the experiments; and through the courtesy

* Read before Section G of the British Association. Dublin meeting.

and assistance of Mr. Westinghouse, by whom the recording apparatus was designed. The author was assisted in making the experiments, and in their reduction, by Mr. Horace Darwin.

The experiments were made on the Brighton Railway, with a special van constructed for the purpose; it was attached to an engine, and was run at various speeds, during which time various forces were measured by self-recording dynamometers. These dynamometers were designed by Mr. Westinghouse; Their principle is that the force to be measured acts on a piston fitting in a cylinder full of water, and the pressure of the water is measured by a Richards' indicator, connected by a pipe to the cylinder; thus, as the drum revolves, diagrams are obtained, giving the force acting on the piston. The advantages of this method are obvious, as the indicator can be placed at any convenient point, and the inertia of the water tends to make the pencil keep a position corresponding to the mean force.

The pistón, and what answers to the cylinder, would be better described as a ring fastened to the edge of a cylindrical box. The rod by which the thrust is to be measured is transmitted to the piston. This piston merely consists of a cast-iron disc, with a cavity in its center, in which the rounded end of the rod rests, and a projecting piece at its center on the other side acts as a guide. The ring, which takes the place of the cylinder, is of the same thickness as the piston, and in its center the piston fits. This ring is screwed to the edge of a cylindrical box, to which the ring with the piston thus forms a cover. The piston fits so as to slide easily, with but little friction, and is made water-tight by placing a disc of india-rubber under it, which is fastened to the center of the piston by a brass collar, and has its edges clamped in between the ring and the edge of the cylindrical box. Thus we have a perfectly water-tight piston, which will move with very little friction, and as its movement is very small, the disturbing effect of the india-rubber at its edge may be neglected; thus the indicator will register the forces acting on the piston by means of the pressure of the water. The pipe leading to the indicator is screwed into the socket. We will neglect the valve for the present, and explain its use a little further on. Suppose the whole apparatus to be filled with water, and that a force were applied to the piston by the rod, it would force some of the water out of the vessel through the opening into the indicator cylinder; the area of the indicator piston is half a square inch, and its maximum range .8 of an inch, therefore the quantity of water required to make a maximum movement of the pencil is 0.4 cubic inches, and as the area of the piston is 30 square inches, its movement would only be 0.013, or $\frac{1}{75}$ inch, which is such a small movement that the india-rubber will introduce no appreciable error. Now, if the indicator piston did not leak, and if it were possible to keep exactly the right quantity of water in the apparatus, nothing more would be required to make it work properly, but as this is evidently impossible, the supply valve becomes necessary. A small pipe, leading from an accumulator loaded to a greater pressure than can ever arise in the vessel, is screwed into the socket; the excess of pressure on the outer side tends to close the valve; there is also a spring which forces the valve on to its seat. This valve is seated with india-rubber, and is made perfectly water-tight. The spindle passes up so as very nearly to touch the brass collar on the underside of the piston. Suppose the whole apparatus to be filled with water when there is no force acting on the piston; then if a force is applied, this will move the piston downwards, so as to send some water into the indicator, and raise the pencil, and will also open the valve, and, as the pressure in the accumulator is in excess of that in the vessel, the water will enter, and go on entering till the piston is raised and no longer opens the valve. Now, if the force on the piston be removed, the indicator spring will force a quantity of water less than 0.4 cubic inches back into the vessel and raise the piston less than $\frac{1}{75}$ inch, and thus the piston can only move $\frac{1}{75}$ inch above the position in which it touched the valve. Again, if we suppose a smaller force to be applied to the piston, it will not be pressed down so far, and will not open the valve unless sufficient leakage has meantime

taken place to allow the piston to come down through its full distance; thus the valve always keeps the right quantity of water in the apparatus to make it work properly, by occasionally opening and letting in enough water to make up for leakage.

A special brake van was built by the London, Brighton, and South Coast Railway Company for these experiments, to which the Westinghouse automatic brake was applied, with four dynamometers, like the one described, attached to it. Nos. 1 and 2 measured the retarding force which the friction of the brake-blocks exert on the wheels; No. 3, the force with which the blocks press against the wheels; No. 4, the force required to drag the van. The arrangement of the levers for applying the brake is not the same as that used on the ordinary rolling stock of the Brighton Railway, but has been slightly modified by Mr. Westinghouse in order to make the pressure equal on both sides of the wheels, and to provide for the application of the dynamometers. Into the cylinder belonging to the Westinghouse brake apparatus the compressed air flows from the reservoir when the brake is applied, and forces the two pistons apart, thus moving the two rods outwards, and by means of their levers, pressing the brake-blocks against the wheels. It is evident that the pressure must be equal on each side of the wheels, and that the pressure on the dynamometer No. 3 must be equal to the thrust on the rod, and hence proportional to the pressure on the wheels. The lever pivoted at its center will evidently tend to turn with a moment equal to the retarding moment exerted by the friction of the brake-blocks on the wheels; and hence the dynamometers Nos. 1 and 2 will register forces proportional to this moment. The brake could be applied to all the wheels of the van, but during the experiments it was only applied to the pair of wheels to the levers of which the dynamometers were attached. Dynamometer No. 4 is connected to a draw bar by a lever, and thus registers the force required to draw the van.

A self-recording speed indicator was used, designed by Mr. Westinghouse. This instrument has been repeatedly tested, and was used at the brake trials on the North British Railway, and on the German State Railway. It consists of a small dynamometer made on the same principle as that just described; it measures the centrifugal force of two weights, which are made to revolve by a strap from a pulley on a shaft driven by friction gear from the pair of wheels to which the brake was applied; a Richards' indicator being used, as in the other dynamometers. Thus, as the centrifugal force varies as the square of the velocity, the speed is got by taking the square root of the ordinates at any point. There is also a Bourdon gauge attached to the above small dynamometer, with the face divided in such a way that the hand shows the speed in miles per hour.

These diagrams thus show the speed of the pair of wheels to which the brake was applied, and therefore the velocity of the train at the moment of applying the brake and subsequently—provided there is no slipping. Any variation in the speed diagram is due to the wheels slipping, and shows to what extent and in what way the brake stops the wheel.

Two of Mr. Stroudley's indicators were fixed side by side in the van; one attached to the axle belonging to the braked wheels; the other to the axle which was running free. The difference of these indicators showed if slipping took place.

Speed indicators were also attached to the van; but these do not register automatically.

The distribution of the weight of the van between the two pairs of wheels was obtained, as well as the weight of the wheels and axles themselves.

In order to ascertain the weight thrown on the braked wheels during the progress of the experiment, a dynamometer fitted to the springs of the van showed the weight at every moment carried on the unbraked wheels, from which information it was easy to deduce the weight on the braked wheels.

The indicators are all placed on a table in the center of the van, and the drums are made to revolve by the cords being wound up on pulleys on the shaft. This shaft is turned at a uniform rate by a water-clock. This clock merely consists of a plunger sliding in a cylinder through a water-tight packing, and loaded with a heavy weight; it is wound up

by connecting it with the accumulator, and at the beginning of each experiment a small cock is opened, which allows the water to run out and the weight to fall, which thus turns the indicator down, and at an ascertained uniform speed. Thus the ordinates of the diagrams taken from these indicators show the various forces, and the abscissæ the distance moved through by the van.

In these experiments the tyres were of steel, and the brake-blocks of cast iron.

The apparatus was designed by Mr. Westinghouse, and constructed under his supervision by the Brighton Railway Co., through whose assistance these experiments were carried into effect.

The effect of applying the brake to the wheels is two-fold. So long as the wheels to which brakes are applied continue to revolve at the rate of rotation due to the forward movement of the train, the effect of the blocks is to create retardation by the friction between the block and the wheel; but when the pressure applied to the block causes the friction to exceed the adhesion between the wheels and rail, the rotation of the wheels is arrested, and the wheel becomes fixed and slides on the rail, being held in its fixed position by the brake-blocks.

Therefore the experiments give the co-efficient of friction:—

1. Between the brake-blocks and the wheel, which is equal to

$$\frac{\text{the tangential force}}{\text{the pressure applied.}}$$

2. Between the wheel and the rail, which is the

$$\frac{\text{friction of the brake-blocks}}{\text{weight upon the wheels.}}$$

They moreover afford a measure of the adhesion between the wheel and the rail.

It has been generally stated that there is no difference in the co-efficient of friction observed in the case of bodies at rest, *i.e.*, in a condition of static friction, and the co-efficient of friction in the case of moving bodies, *i.e.*, in a condition of kinetic friction; but Mr. Fleeming Jenkin, in his paper read before the Royal Society, in April, 1877, upon the friction between surfaces moving at very low speeds, alludes to the fact that in cases where a difference in the co-efficient of friction is observed between static and kinetic friction, the static friction exceeds the kinetic.

Coulomb also points out his experiments that in the case of static friction the co-efficient of friction increased with the time during which the bodies had been at rest.

The experiments of Coulomb, Rennie, Morin, and Jenkin, were made with bodies moving at comparatively low velocities.

The table (p. 523) shows the mean results obtained from a large number of the experiments made with the apparatus above described, upon the action between the cast-iron brake-blocks and the wheels fitted with steel tyres.

A limited number of experiments were made with wrought iron blocks upon the steel tyre, a mean of which gave the following result:—

Average.		Co-efficient of Friction between Wrought Iron blocks on Wheels.			
Miles per Hour.	Feet per Second.	At Commencement of Experiment to 3 Seconds.	At from 5 to 7 Seconds.	At 12 to 16 Seconds.	At 24 to 25 Seconds.
48	..	.110	..	..	..
31	..	.129	.11	.099	..
18	..	.170	..	..	..

The following table shows the result obtained by the sliding of the wheel on the rail, that is, a steel tyre and steel rails:

Average.		Co-efficient of Friction between Wheel on Rail, Steel on Steel.			
Miles per Hour.	Feet per Second.	At Commencement of Experiment to 3 Seconds.	At from 5 to 7 Seconds.	At 12 to 16 Seconds.	At 24 to 25 Seconds.
50	..	.04	..	..	..
45	..	.051	..	..	..
38	..	.57	.044	.044	..
25	..	.080	.074	..	..
15	..	.087	..	..	..
10	..	.110	..	..	..

Average.		Co-efficient of Friction between Cast-Iron Brake Blocks and Steel Tyres of Wheels.			
Miles per Hour.	Feet per Second.	At Commencement of experiment, *e. g.*, to Three Seconds.	At from 5 to 7 Seconds.	At 12 to 16 Seconds.	At 24 to 25 Seconds.
60	88	.062	.054	.048	.043
55	..	..	..	..	..
50	73	.100	.070	.056	..
45	65	.125	..	..	..
40	58	.134	.100	.080	..
30	43	.184	.111	.098	..
20	29	.205	.175	.128	.070
10	14	.320	.209	..	..
Under 5	7	.360	..	..	..
Fleeming Jenkin, Steel on steel dry.....	.0002 to .0086	.351 mean .365 max.	..	..	..
Morin, Iron on iron.....	..	.44	..	..	..
Rennie, At pressure of 1.6 cwt. per square inch wrought iron on cast iron.....	..	.275	..	..	..
" —Steel on cast-iron.	..	.400	..	..	..

The general results of these tables show that the co-efficient of friction between moving surfaces varies inversely in a ratio dependent upon the velocity at which the surfaces are moving past each other; probably the equation would be of the form of $\frac{a}{b+v}$.

The co-efficient of friction, moreover, at these velocities becomes smaller also after the bodies have been in contact for a short time. That is to say, the longer the time the surfaces are in contact, the smaller apparently does the co-efficient of friction become. This result appears more marked in the case of cast-iron blocks than of the wheel sliding on the rail, at all events for the first thirty seconds of the contact, the arrangement not admitting of the experiments being carried on for a longer time. This effect, however, does not appear to be unnatural, as the friction develops heat, and the consequent expansion tends to close up the pores, and to make the heated surface a more united surface than the colder surface. Besides which, it is probable that in the act of rubbing, small patches may be detached, which may act as rollers between the surfaces.

It will also be observed that the co-efficient of friction between the cast-iron block and the steel tyre is much larger than that between the steel tyre of the wheel and the rails, which are also generally of steel.

As has been above mentioned, the sliding of the wheel on the rail takes place when the friction of the brake-blocks is greater than the adhesion between the wheel and the rail, which is due to the weight upon the wheel. This was found to amount generally to about 24 to 28 per cent. of the weight.

The influence which these results have upon brakes for railway trains may be briefly summarized as follows:—

1. The application of brakes to the wheels, when skidding is not produced, does not appear to retard the rapidity of rotation of the wheels.

2. When the rotation of the wheels falls below that due to the speed at which the train is moving, skidding appears to follow immediately.

3. The resistance which results from the application of brakes without skidding is greater than that caused by skidded wheels.

4. The pressure required to skid the wheels is much higher than that required to hold them skidded; and appears to bear a relation to the weight on the wheels themselves, as well as to their adhesion and velocity.

In order to produce a given result at different velocities, the pressure applied to the brake-blocks must vary in the proportion shown by the co-efficient of friction.

Thus at 50 miles an hour the pressure required to make one pair of wheels

slide on the rail was nearly 27,000 lbs., whilst at 20 miles an hour a pressure of about 10,300 lbs. was found sufficient to obtain the same result.

The strain on the draw-bar showed that the retarding force or the tangential strain between the brake-blocks and the wheels followed very nearly the same law of variation. This is to say, in order to produce a degree of friction on the wheel at 50 miles an hour which shall exert a retarding force on the train equal to that at 20 miles an hour, the pressure applied to the brake-blocks at 50 miles an hour must be nearly two and a half times as great as that required at 20 miles an hour, and a still greater pressure is required for higher velocities.

Therefore, whilst a comparatively low pressure would make the wheels slide at low velocities, it was difficult to obtain any sufficient pressure to make the wheel slide at velocities over 60 miles an hour.

The figures given in the above tables must at present be accepted as only provisional, until an accurate mean has been obtained from the diagrams, which are not yet all worked out. But it may be assumed as an axiom that for high velocities a brake is of comparatively small value unless it can bring to bear a high pressure upon the surface of the tyre almost instantaneously, and it should be so constructed that the pressure can be reduced in proportion as the speed of the train is reduced, so as to avoid the sliding of the wheels on the rails.

EXPERIMENTS ON THE HEIGHTS, &C., OF JETS FROM THE HYDRANTS OF THE KINGSTON WATERWORKS, JAMAICA.

By FELIX TARGET, Assoc. Inst. C. E.

From Proceedings of the Institution of Civil Engineers.

Numerous experiments were made with nozzles of various sizes and different lengths of hose, attached to hydrants on the street mains, which mains were of varying diameter. The accompanyiny table (see p. 525) gives the results of some of the experiments, those cases best suited for comparison having been selected. The height of the jet was measured from the outlet at the nozzle to the upper part of the curved spray described by the jet. The copper hand-pipe, 4 feet in length, was always held breast-high, with the nozzle 5 feet to 6 feet off the ground. The leathern hose was of the kind ordinarily used in London, $2\frac{1}{2}$ inches in diameter and in lengths of 40 feet. The hydrants and stamp pipes were Bateman and Moore's. The mains were nearly new, and were coated inside with Dr. Angus Smith's preparation. The draught of water for the town for twenty-four hours was equal to 1,266,600 gallons, the maximum per hour being 93,000 gallons. During the time the experiments were carried on the draught was 45,000 gallons per hour, which is the average night consumption. The experiments were made in the early morning in a still atmosphere.

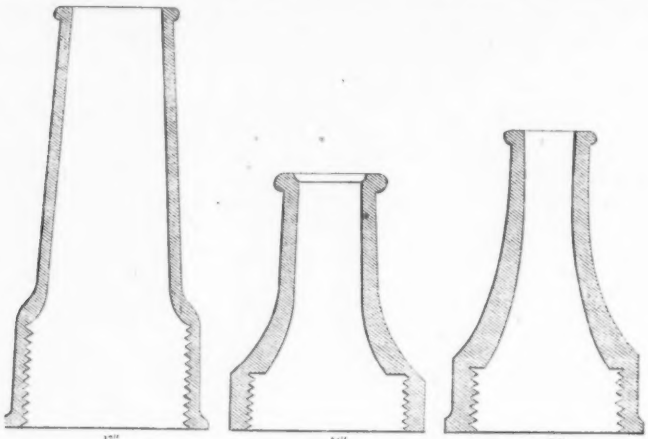
The accompanying figures show the forms of three of the nozzles. Up to the highest pressures the $\frac{1}{4}\frac{3}{2}$ inch nozzle threw a much more compact jet, with less spray, than either the $\frac{1}{4}\frac{4}{8}$ inch or the $\frac{1}{4}\frac{1}{6}$ inch nozzle, the smaller of which occasioned the greatest spray. The heights are only correct within a few inches, as the jets slightly varied during the time of the experiments, notwithstanding that the pressure gauge, which was used to ascertain the head of water, remained nearly steady.

From these experiments it is difficult to arrive at any correct law, or formula, for calculating both the height and the delivery of water from jets in a town. It is evident, however, that with high pressures, although the 2-inch mains are large enough to furnish an ample and constant supply to forty houses, each drawing from 200 gallons to 500 gallons per day, yet they are undoubtedly too small for fire purposes without the aid of a fire engine.

The four inch mains gave results

RESULTS OF EXPERIMENTS ON THE HEIGHTS OF JETS, DELIVERY OF WATER, ETC., AT THE KINGSTON WATERWORKS, JAMAICA.

1 Number of experiment.	2 Size of Nozzle in Inches.	3 Height of Jet in Feet.	4 Number of Gal. p. Min.	5 Head in feet at Hydrant.	6 Length of Main in Yards.
No. 1. — With one length of hose.	1 7/16	20½	92	53½	1,083 of 21-inch.
	1 1/2	34½	55	..	+ 50 of 4-inch.
Ditto, with three lengths of hose.	1 7/16	18	..	..	
	1 1/2	29½	..	..	
No. 4. — With one length of hose.	1 7/16	38	122	92	1,585 of 21-inch.
	1 1/2	44½	73	..	+ 133 of 12-inch.
	1 1/16	44	66	..	
No. 5. — With one length of hose.	1 7/16	9	66	92	1,585 of 21-inch.
	1 1/2	25	55	..	+ 183 of 12-inch.
	1 1/16	27	47	..	+ 66 of 2-inch.
No. 6. — With one length of hose.	1 7/16	55	138	122.4	1,585 of 21-inch.
	1 1/2	68	94	..	+ 600 of 12-inch.
	1 1/16	77	73	..	+ 116 of 4-inch.
Ditto, with three lengths of hose.	1 7/16	48½	..	..	
	1 1/2	62	..	..	
	1 1/16	66	..	..	
Ditto, with six lengths of hose.	1 7/16	26½	100	..	
	1 1/2	51½	82	..	
	1 1/16	62	69	..	
No. 7. — With one length of hose.	1 7/16	7	52	122.4	1,585 of 21-inch.
	1 1/2	24	47	..	+ 600 of 12-inch.
	1 1/16	27	..	..	+ 166 of 4-inch.
					+ 20 of 2-inch.
No. 9. — With one length of hose.	1 7/16	11½	60	106	1,585 of 21-inch.
	1 1/2	32	47	..	+ 266 of 12-inch.
	1 1/16	32	..	..	+ 60 of 4-inch.
					+ 100 of 2-inch.
Ditto, with three lengths of hose.	1 7/16	12	..	..	
	1 1/2	29	..	..	
	1 1/16	32	..	..	
No. 13.—With one length of hose.	1 7/16	58	136	156	1,585 of 21-inch.
	1 1/2	85	130	..	+ 1,266 of 12-in.
	1 1/16	84	94	..	+ 116 of 4-inch.
Ditto, with three lengths of hose.	1 7/16	48	180	..	
	1 1/2	64	132	..	
	1 1/16	62	94	..	
Ditto, with five lengths of hose.	1 7/16	41	143	..	
	1 1/2	55	132	..	
	1 1/16	62	103	..	
No. 14.—With one length of hose.	1 7/16	15½	73	154¾	1,585 of 21-inch.
	1 1/2	28	73	..	+ 1,266 of 12-in.
	1 1/16	35	60	..	+ 70 of 4-inch.
					+ 87 of 2-inch.
Ditto, with three lengths of hose.	1 7/16	18½	78	..	
	1 1/2	29	68	..	
	1 1/16	46	66	..	
Ditto, with five lengths of hose.	1 7/16	14½	70	..	
	1 1/2	26	66	..	
	1 1/16	35½	55	..	
No. 20.—No hose. Direct from 2-inch main	1 7/16	10½	64	157	1,585 of 21-inch.
	1 1/2	22½	55	..	+ 1,050 of 12-in.
	1 1/16	37	60	..	+ 125 of 4-inch.
					+ 111 of 2-inch.



Scale ½ full size.

nearly equal to the 12 inch mains with an effective head of 155 feet. Taking height and quantity into consideration the 14/16 inch nozzle with the higher pressures appeared to give the best results.

THE PREVENTION OF RAILWAY AND STEAMSHIP ACCIDENTS.*

By Professor OSBORNE REYNOLDS.

From "Iron."

The past twelve months has been no ordinary period. Political events of the very first magnitude have followed each other in rapid succession, and the mechanical events have been of such vast importance and interest that they have successfully competed with their political rivals, and have secured for themselves no ordinary amount of public interest.

Railway and steamship disasters of this year are calculated to impress upon us that, take what precautions we may, we cannot do away with accidents altogether. We must face the risk, and all we can hope to do is to reduce this risk to a minimum. It is to questions concerning this minimum risk that I wish to direct your attention.

The attention paid to the means of preventing accidents and mitigating the consequences has been steadily growing, and during the last few years it has been considerable; and this not only by engineers and those more directly concerned with the accidents, but also by the public and the Legislature. The aid of Parliament has been claimed in almost every direction, and numerous important statutes have been passed with a view to diminish risk. The object of this attention has not been solely the means of locomotion, but has embraced every species of mechanical appliance in the use of which there is risk to human life; and it is only for the purpose of reducing my subject within reasonable limits that I shall confine myself to considering some of the risks attendant upon locomotion. That rapid locomotion can never be altogether rendered free from risk will, I think, be generally

* An address before the Scientific and Mechanical Society of Manchester, England.

admitted. It is the conclusion which must be drawn from the experience we meet with in the exercise of our natural powers. For all animals, when in their natural state, do meet with accidents in consequence of their movements. And adopting the now generally accepted hypothesis as to the survival of the fittest, we at once see that the limit which exists to the size and speed of animals is only maintained in virtue of the increase of the accidents consequent on any overstepping of these limits.

From the fact that man has already gone beyond nature in the size and speed of his locomotive structures, it may be thought that when design comes in, the laws found to hold in natural selection no longer apply. Further consideration, however, will show that this is by no means the case. It is true that in our railway trains—to take the most striking instance—we have far exceeded the size and considerably exceeded the speed of any walking or running animal. But, think for one moment! How have we done this? Simply by modifying the conditions under which the movement is accomplished. All animals, as far as nature has selected them, have been selected to exercise their powers under the conditions at the surface of the earth as these conditions exist; whereas our locomotive engines are possible only after the conditions have been completely modified by the construction of railways. Even our carriages and teams of horses would be altogether useless were it not for the existence of good roads. Thus we see that it is not as a constructor of locomotive machines that man has won the race, but by laboriously modifying the conditions which these machines have to meet.

Thus, in considering the liability to accident in the means of locomotion constructed by man, as compares with the liability to accidents met by animals in the exercise of their natural powers, it must be remembered that failure in the due maintenance of the two conditions—the improved road and the rule of the road—may be important elements in the former.

As far as ships are concerned, the last is the only condition. Here there is no improvement in the road, and no artificial guides, such as in the railway insist, to a certain extent, on the maintenance of the rule of the road.

In virtue of the smoothness of the railway we can pass the natural limits as regards size and speed of locomotive structures, and in virtue of the rule of the road we do away to some extent with the necessity for such comparatively great powers of stopping and turning as those possessed by swift annimals; but we cannot do away altogether with the necessity for such powers, and in spite of all possible improvement in the conditions under which locomotion takes place, it would appear that the minimum of these powers consistent with safety remains fixed by the surrounding conditions. For there are certain conditions which play an essential, although it may be thought a secondary, part in our means of locomotion, which conditions, it may appear, that we have no power to modify to any great extent. These relate to the distances at which we can see and hear. Although by the use of telescopes we may increase the optical power of our eyes to almost any extent, it is found that such an increase is of no use to us in guiding ourselves or our structures amongst obstacles on the earth's surface; the limits to the distance at which we can see such obstacles being fixed by the form of the earth's surface and the condition of the atmosphere, rather than by the power of our eyes. These conditions vary greatly. In some places, and at some times, a signal may be visible for miles, while at other times it may not be visible many yards. When the conditions of the atmosphere are such that they limit this distance, no increase in the power of our eyes would make any difference; and their power is amply sufficient when the distance is not otherwise limited.

The effect of these conditions is much more important as regards safe navigation at sea than as regards the driving of our trains. Dwelling for one moment on ships, we see at once how this limit to the distance at which we can depend on our eyes and ears to warn us of danger, must place a limit on the size and speed of our vessels. Large and swift vessels will only have the same room in which to manœuvre out of danger as small ones. Hence, in order that they may as successfully accomplish such manœuvres,

the large and swift vessels should have proportionately much greater powers of stopping, starting and turning than small vessels. Up to the present time, however, no means have been found of rendering the manœuvring of large ships proportionately greater than the manœuvring power of small ships.

To railway trains the same law does not apply with the same force; still, it does apply. We have not made our system of distance signalling so complete but that there do continually arise cases in which the first warning the engine-driver receives of an obstruction ahead is from the obstruction itself; and under these circumstances the chance of safety lies in the power of stopping the train within the limited distance. In such cases the power of stopping with a heavy fast train, in order to give the same chance of safety, must be proportionately greater than with a slower and lighter train.

It is certain that we have not as yet developed to the utmost the brake power on our trains, or the steering and stopping powers of our ships; but it is certain that there is a limit to these powers, and the only question is, how far are we from this limit? This brings me to what is, to me, the most pleasant part of my subject, namely, the consideration of certain progressive steps that have recently been made, which, although they have not attracted much notice, are nevertheless extremely important to our means of locomotion, and are also important as showing that however far happy guess-work may carry us towards perfection, perfection itself is rarely, if ever, to be attained except by scientific method.

Up to within the last few years our attention has been so closely occupied in developing and perfecting the primary power in our means of locomotion, that but little notice has been paid to such secondary considerations as the powers of stopping, starting, or turning, as the case may be; for these such appliances as came at once to hand were at first deemed sufficient; thus hand brakes on those parts of the train where they could be at once applied, and the rudder and hand wheel, such as may be said to have grown on the sterns of ships, were accepted without question. And it was only when we had so far perfected our locomotive structures as regards what may be called their locomotive functions that they have outrun our means of holding them; and when the alterations in the conditions consequent on the increase of traffic (of which I shall have more to say presently) have increased the necessity for greater powers of avoiding each other, we find ourselves driven to consider how far the power of stopping and turning may be improved.

As regards railway trains the question has been very widely taken up. The great prize held out to the inventor of the best continuous brake brought many able competitors into the field, while the urgency of the case has led to the adoption of much more direct means of testing the merits of the various inventions than ever fell to the good fortune of other inventors.

The result appears likely to be very instructive, apart from the direct object involved. It appears likely to afford an illustration of the fact that it is no use attempting the solution of such a problem except by the thorough and scientific method.

The stopping power arising from a single brake was known to depend on the tightness with which the brake blocks were screwed against the wheels up to a certain point; and it was apparently obvious that the tighter the better until the wheels no longer revolved—until, in fact, the wheels were skidded—to produce the greatest effect; therefore, it was thought that all the guard or driver had to do was to skid his wheels. Hence, when an emergency arose, the brakes were invariably screwed home and the wheels skidded. This practice, which has prevailed without question for forty years, is an instance of how far general experience can be depended on to remove a misconception. It is now found for the first time that by skidding the wheels the brake loses nearly half its greatest power of stopping the train. If the brake is applied with the greatest force short of skidding the wheels, the train will stop in something like half the distance required if the wheels are skidded.

How many lives have been sacrificed to this misconception it is not pleasant to think. Thanks to Captain Galton, it

is now removed, and it now only remains to choose the best means of applying the brakes so as to produce the greatest effect. Captain Galton has shown us the greatest stopping power we can obtain from one pair of wheels, and when we have succeeded in obtaining this from every pair of wheels on a train we shall have reached the minimum limit of our stopping power. But this is something like four times greater than the stopping power of ordinary trains.

Turning now to the manœuvring powers of steamships, I come to the subject which has engaged no small part of my attention for several years. The manœuvring powers of ships involve not only their power of stopping, but also their means of turning, and as regards improvement, the question of turning is the more important, for, as regards powers of stopping, a sailing ship has none other than that of turning her head into the wind; while with steam ships their greatest stopping power is developed by the reversal of their engines; and as they are all provided with the power to reverse, the only question is as to the rapidity with which it can be accomplished; and in this respect there is not great room for improvement. So far it has been the almost universal custom to reverse the engines by hand, and in the case of large engines the operation might occupy as much as thirty seconds, which would be time lost. Recently, however, steam reversing gear has come into vogue for large vessels, and by means of this the engines can be reversed by a mere turn of the wrist. We cannot, therefore, hope to increase the powers which vessels have of stopping themselves. As regards a vessel's power of turning, however, it is different. Taking screw-steamships as being the most important class of ships, and those to which, owing to their great speed, manœuvring powers are most important, we may see from the very great number of collisions in which screw-steamers take a part that, as at present sent to sea, the turning powers of these vessels are altogether insufficient. We all saw an authoritative statement that there had been upwards of seventy collisions in the Thames alone within twelve months, and that in by far the greater part of these collisions a screw-steamship was involved. The insufficiency of the turning powers of screw steamers has long been acknowledged by all those who have to do with them; but, strange to say, until within the last few years, no systematic attempts had been made to remedy the evil. It has been with the steering of screw steamers just as it was with the stopping of railway trains; the rudder and hand wheel, like the brakes on the engine and tender, came ready to hand when steamers were first introduced. And hitherto gross misconception has prevailed. It may be that the fact of the rudder and wheel having held its own for so long on sailing ships led to the conviction that it was already proved to afford the best means of steering, and as the rudder of the steamer was itself similar to that of the sailing vessel, and was similarly placed—namely, at the stern—it was assumed that it must produce the same effect. Such views would gather strength from the fact that in paddle steamships the rudder was found to answer its purpose as well as in the sailing ships. At any rate, for some twenty years no attempts were made to investigate the action of the rudder in screw-steamers, although from the time of the first screw-steamer going to sea anomalies in the steering presented themselves.

The action of a rudder at first sight appears to be so simple and obvious that it seems as if nobody thought of looking closer into the question. The rudder appears to act the simple part of a guide to the stern of the ship. When straight the rudder allows the ship to go straight on, but when it is turned it then guides the stern of the ship out of the direction in which the head is moving, and so causes the ship to turn. This is the apparent action of the rudder, and this would be its action if the ship did not offer any resistance to be turned. Owing to this resistance, however, and to the yielding nature of the water, the rudder does not act the part of a rigid guide to the stern of the ship, but only exerts what may be called a tendency to guide the stern. This, also, is to a certain extent obvious. And it is also obvious that by increasing the size of the rudder the tendency which it exerts to guide the stern will be increased. But what is not obvious, and what was not seen until

recent years is, that the tendency which the rudder exerts is not due solely to the forces which act between the water and the rudder, but to the increased pressure of the water which the rudder causes against that side of the ship towards which it is turned. The importance of this fact being entirely overlooked, it was not seen that the opening of a large space, such as the screw-way immediately in front of the rudder must in itself greatly diminish the tendency of the rudder to guide the ship. And further, such was the confidence in what may be called the obvious action of the rudder, that when it was found, as it was immediately on the introduction of screws, that, no matter how fast a vessel might be going through the water, if the screw was stopped or reversed the action of the rudder was not only feeble but uncertain, it was not supposed that this effect was due to any change in the tendency which the rudder exerted to turn the ship, but that it was due to the tendency which the screw exerted to counteract the effect of the rudder.

This blind confidence in the consistent action of the rudder, whatever may appear to the contrary, is so strong even at the present day, that, although from his own experience when manœuvring his ship in rivers and in port, every captain and pilot knows that his rudder is all but useless to him whenever his screw is stopped or reversed, and his vessel still be moving forward slowly, numerous pilots and captains adhere to the opinion that such would not be the case if the vessel were moving fast, for then, they argue, that the action of the rudder would be sufficient to counteract the action of the screw; and so great is their confidence in this view that they never try the experiment but wait until a collision is imminent, and then when, perhaps, as in the case of the *Konig Wilhelm* and the *Kurfurst*, the ship, with her screw reversed, pursues her own unguided way right into the sides of another, they refuse to give up their confidence in their rudder, and maintain, in spite of all evidence to the contrary, that their orders could not have been obeyed. The whole error arises from a failure to grasp the circumstances on which the action of the rudder depends. As long, and only as long as the water is rushing backwards past the rudder, will the rudder exert its normal tendency to guide the ship.

This is no mere theory. For, at the instance of a committee of the British Association, experiments to test these conclusions have been made on twelve steamers ranging from 4000 tons downwards; and in every case it is found that, no matter how fast the ship may be going, the instant the screw is reversed the action of the rudder is also reversed, and rendered comparatively feeble. It is therefore now conclusively shown that it was a misconception to suppose that the rudder would exert its usual influence with its screw stopped or reversed. And there can be no doubt that but for this misconception, many collisions might have been prevented.

The result of these experiments has been to bring to light what the manœuvring power of screw-steamers really is, and hence to clear the way to making the best possible use of that power.

Inefficient as a rudder on a screw-steamer must always be under certain circumstances, with large vessels its inefficiency is greatly increased by the insufficient means provided for turning it in case of emergency.

This evil might at once be remedied. Nothing is easier than to apply some power in place of the hand-wheel. Various contrivances for doing this have already been devised; and there is no doubt that the inventor of the best steering apparatus will secure a prize nearly, if not quite equal to that which will fall to the inventor of the best brake. The experience just mentioned as regards brakes may, however, be taken as a caution by those whose interest it is to find the best steering apparatus. Just as the question of the best brake is now found to lie beyond the mere means of applying it, so the best steering apparatus may be found to involve more than the mere means of turning the rudder.

It may be that the whole power of the engines of a ship will be brought to bear in bringing her round. Indeed, this has been already done in the instance of twin screws; and certain recent inventions are said to apply this power at still greater advantage. As regards the turning power of ships, therefore, it is

clear that although there doubtless is a limit, yet, owing primarily to ignorance as to what the turning powers of our screw-steamers really are, and also to the insufficient power now applied to turn the rudders, we are far from having reached the limit; and we may fairly hope that the risk at present attending the navigation of screw-steamers will, inasmuch as it depends on the want of turning power, be considerably reduced.

That we shall eventually develop to the utmost the powers of stopping and turning, whether on railways or on ships, and make use of all our scientific knowledge to discover those methods, may, I think, well be argued from the progress of late years. Although time has not allowed me to enter upon them in this address, there are many other circumstances under our control which affect the risk of locomotion beside the adequacy of the powers of manœuvring. And it is very satisfactory to notice that as regards one of these circumstances, and the one to which, until recently, accidents were mainly to be attributed, we appear, at all events, as judging from the accidents of this year, to have reached perfection. This is the adequacy of the strength of our structures. It is but rarely now that we hear of a railway axle, a rail, a beam, or even a boiler, breaking under its legitimate load. This certainly has only been reached by the most elaborate research, aided by scientific knowledge, and by the institution of most careful systems of tests and periodic inspection. But these have all been done, and we may fairly hope that what has been accomplished in one direction will be followed in others until we shall have substituted throughout every department of the manufacture and working of our structures a thoroughly understood art for what was a few years ago merely a field for ingenuity.

But it must not be imagined that all the future improvements there may be in the stopping power of our trains or in the turning power of our steamboats, or in whatever may affect their safety, will all be allowed to go to diminish the risk. As the risk with structures at their present sizes and moving at their present speeds is diminished, it will probably be as it has been—the sizes and speed will be increased, and more than this. I have already mentioned the increased risk consequent on the increased traffic of our railways and the increased crowding of our seas. This crowding goes to form one of the conditions under which locomotion has to be accomplished; and it is most important to notice that this crowding can itself only be limited by the increased risk which it causes.

Inasmuch as the risk of locomotion depends upon crowding so far, any diminution to risk which may be accomplished by increasing the manœuvring powers of our locomotive structures seems likely to be followed by increased traffic and crowding, and thus the advantage derived on the one hand may be balanced by the disadvantage on the other.

It thus appears that after all precautions risk is a necessity of locomotion, and that the speed and size of our structures as well as the extent of the possible traffic are limited by the risk. And it may well be asked, what, then, is the limit to the risk? This is a question of morality. The limit to the risk is the extent of risk to which we are willing to run. To accomplish some object or even to save ourselves trouble we are all of us willing to run some risk. Let our system of working be ever so perfect, the immunity from accidents will result in neglect, and this must culminate in accidents. The loss of the *Eurydice* appears to have been a marked instance of this, as does also the Sittingbourne accident, and it does not appear impossible that this may also have to be said of the loss of the *Princess Alice*.

Notwithstanding all this, statistics show us that the risks are and have been steadily diminishing. Nor is this diminution of risk other than we should expect. As novices we put up with that which experience teaches us to withstand, and hence, as we become more familiar with the incidents of traveling, we come to object to risks of travelers and responsibilities of officials which we know may be reduced.

It is proposed to hold an international industrial exhibition in Glasgow in 1880, the matter being in the hands of a number of influential citizens headed by the Lord Provost.

THE RECTANGLES THAT MAY BE INSCRIBED IN A GIVEN RECTANGLE.

By Professor W. ALLAN.

Written for Van. Nostrand's Engineering Magazine.

Having seen several allusions to this problem of late I am induced to send you the following discussion of it. The problem has a useful application in the construction of Howe trusses and of similar structures.

I. To determine generally the rectangles that may be inscribed in a given rectangle, ABCD.

Assume some point as H, on the shorter side of the given rectangle, as one of the vertices of an inscribed rectangle. Let its distance from A be $= x$. Then through this point describe a circle with its center at O, the center of ABCD. The points in which this circle cuts the sides of ABCD are the points of the vertices of the inscribed rectangles that are possible when our first assumed point is one of these vertices. Each of the eight points gotten may serve as one of the vertices of two rectangles (like those having a common vertex at F). The two rectangles that may be drawn at each set of two points will evidently in every case be like those at F. No other rectangle, save those in the figure, can be inscribed with a vertex at F.

These rectangles have some pretty relations.

Let a=AB=shorter, and b=AC=longer side of given rectangle. Let AF $=y$, AH$=x$. Then FC$=b-y$ and HB $=a-x=$AP. From the similar triangles AFP and FCK, we have

$$\text{AP} : \text{FC} :: \text{AF} : \text{CK} = \text{AH} \therefore a-x : b-y :: y : x$$

whence

$$y^2-x^2-by+ax=o \qquad (1)$$

and the value of x in terms of y is

$$x=\frac{a}{2}\pm\sqrt{\frac{a^2}{4}+y^2-by}$$

Let s and p be the sides of the inscribed rectangles. Referring to the smaller of two inscribed in Fig. 1 we see that it, together with four triangles, make up the area of the given rectangle which is equal to ab. The triangles are the two equal ones AFH and GLD, and the other two equal ones FCL and GHB. The area of the first two $= xy$, and of the second

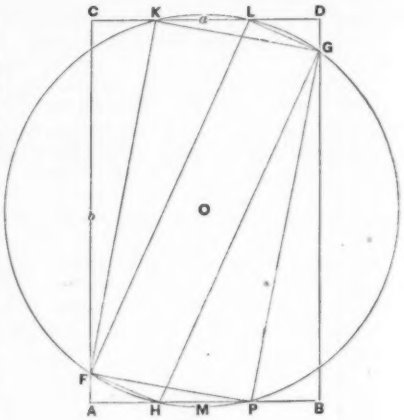


Fig. 1.

two $=(a-x)\,(b-y)$. The area of the rectangle FG$=sp$. Hence

$$(a-x)\,(b-y)+xy+sp=ab$$

$$(b-y)\left\{\frac{a}{2}\pm\sqrt{\frac{a^2}{4}+y^2-by}\right\}$$

$$+y\left\{\frac{a}{2}\pm\sqrt{\frac{a^2}{4}+y^2-by}\right\}+sp=ab$$

$$\therefore sp=\frac{ab}{2}\mp(b-y)\sqrt{\frac{a^2}{4}+y^2-by} \qquad (2)$$

The two values of the area sp correspond to the two rectangles with vertices at F. The *sum* of these two rectangles is seen to be always$=ab=$area of the given rectangle. As the point H is carried towards A, the smaller rectangle diminishes, and the other increases until at the limit one becomes the diagonal AD, and the other becomes the given rectangle itself. As H is assumed nearer and nearer to M (the middle point of AC) the two inscribed rectangles approach each other in size, and when H coincides with M, they become equal, and each is=one half the circumscribed rectangle, ABCD.

II. To determine the sides of the

blocks on which diagonals of a Howe truss abut, so that the faces may be perpendicular to the diagonals.

The face, or hypothenuse of the block (FH, Fig. 1) is equal to the breadth of the brace, and is the dimension given. The relation between this and one of the sides of the block leads, as Prof. Woods remarks in his book, to an equation of the fourth degree, which is insoluble.

But the relation between the *two sides* of the block is given by equation (1)

$$y^3-x^3-by+ax=o$$

This is the equation of an Equilateral Hyperbola, which is shown in Fig. 2.

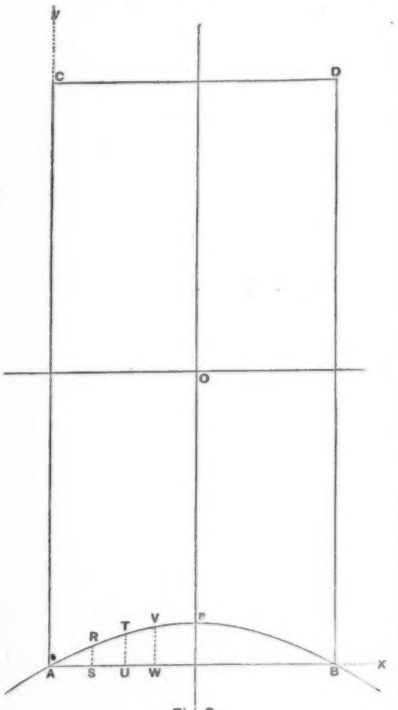


Fig. 2.

Transposing the origin to O the center of ABCD, eq. (1) becomes

$$y^3-x^3=-\tfrac{1}{4}(a^3-b^3) \qquad (3)$$

And O is the center of the Hyperbola. The vertex is V, and the curve passes this A and B. With A as center and radius equal to the given breadth of the base describe a circle. At the point where this circle intersects the Hyperbola within the rectangle, draw the co-ordinates of the Hyperbola referred to A as origin. They are the sides of the block whose face equals the radius of the intersecting circle.

The form of the Hyperbola changes only with the values of a and b. A table may be readily constructed giving the values of the sides of the blocks for given faces when the values of a and b are fixed. The values of these sides may be obtained by measuring the co-ordinates on a carefully prepared drawing, or by measuring one co-ordinate, and then calculating the others by means of eq. (1). A specimen of such a table is appended, when b is taken=20 and a=10:

Face.	x	y	Face.	x	y
0.20	0.18	0.089	2.20	2.03	0.845
0.40	0.37	0.180	2.40	2.22	0.904
0.60	0.55	0.264	2.60	2.41	0.961
0.80	0.73	0.345	2.80	2.60	1.014
1.00	0.91	0.423	3.00	2.80	1.065
1.20	1.10	0.503	3.20	3.00	1.112
1.40	1.28	0.575	3.40	3.20	1.155
1.60	1.46	0.645	3.60	3.40	1.194
1.80	1.64	0.711	3.80	3.60	1.228
2.00	1.83	0.778	4.00	3.80	1.258

In the contribution of Prof. Haupt, published in the November number of our Magazine, the statement was made that the new survey of the Delaware River then in progress was "under the supervision of Capt. S. C. McCorkle." It is desired to explain that Mr. McCorkle was the assistant in charge of the local triangulation. "The topography of that portion of the river shores then being surveyed was under the direction of Assistant R. M. Bache, and the hydrography of the river was executed by Assistant H. L. Marindin, under the special supervision of Assistant Henry Mitchell."

The entire work was organized and directed by Hon. C. P. Patterson, Superintendent of the U. S. Coast and Geodetic Surveys.

ON A NEW METHOD OF DETECTING OVERSTRAIN IN IRON AND OTHER METALS, AND ON ITS APPLICATION IN THE INVESTIGATION OF THE CAUSES OF ACCIDENTS TO BRIDGES AND OTHER CONSTRUCTIONS.

By ROBERT H. THURSTON, C. E.

A Paper read before the American Society of Civil Engineers.

It has been shown by the writer* and by other investigators that, when a metal is subjected to stress exceeding that required to strain it beyond its original apparent, or "primitive," elastic limit, this primitive elastic limit becomes elevated, and that strain-diagrams obtained autographically, or by carefully plotting the results of well conducted tests of such metal, are "the *loci* of the successive limits of elasticity of the metal at the successive positions of set."†

It has been shown by the writer also that at the successive positions of set, strain being intermitted, a new elastic limit is, on renewing the application of the distorting force, found to exist at a point which approximately measures the magnitude of the load at the moment of intermission.‡

It has been still further shown by the writer, and by Commander Beardslee, U.S.N., by direct experiment in the Mechanical Laboratory of the Stevens Institute of Technology, and at the Washington Navy Yard, that the normal elastic limit, as exhibited on strain diagrams of tests conducted without intermission of stress, is exalted or depressed when intermission of distortion occurs, according as the metal belongs to the iron or to the tin class.§ This elevation of the normal elastic limit by intermitting strain is, as has been shown, variable in amount with different materials of the iron class and the rate at which this exaltation progresses is also variable. With the same material and under the same conditions of manufacture and of subsequent treatment, the rate of exaltation is quite definite and may be expressed by a very simple formula. The writer has experimented with bridge material, and Commander Beardslee has examined metal specially adapted for use in chain cables, for which latter purpose an iron is required, as in bridge building, to be tough as well as strong and uniform in structure and composition. The experiments of the latter investigator have extended to a wider range than have those of the writer, and the effect of the intermission of strains considerably exceeding the primitive elastic limit has been determined by him for periods of from one minute to one year.* From a study of the results of such researches and from a comparison with the latter investigation, which was found to be confirmatory of the deduction, the writer has found that, with such iron as is here described, the process of exaltation of the normal elastic limit due to any given degree of strain usually nearly reaches a maximum in the course of a few days of rest after strain, its progress being rapid at first and the rate of increase quickly diminishing with time. For good bridge irons, the amount of the excess of the exalted limit, as shown by subsequent test, above the stress at which the load had been previously removed may be expressed approximately by the formula:

$$E' = 5 \text{ Log. } T + 1.50 \text{ per cent.};$$

in which the time, T, is given in hours of rest after removal of the tensile stress which produced the noted stretch.

Thus, in the figure, which is a facsimile of a part of a strain-diagram produced by such an iron, during a test in which the intermission of stress was of too brief duration to cause an observable exaltation of the normal elastic limit in a diagram drawn on so small a scale, the point E is the primitive elastic limit

* See Trans. Am. Soc. C. E., 1874, *et. seq.*, *Journal Franklin Institute*, 1873; *Van Nostrand's Eclectic Engineering Magazine*, 1873, etc., etc.

† On the strength, etc., of Materials of Construction, 1874, Sec, 20.

‡ On the Mechanical Treatment of Metals; *Metallurgical Review*, 1877; *Engineering and Mining Journal*, 1877.

§ Trans. Am. Soc. C. E., 1877.

* The result on this investigation is completed and will be presented to the President of the United States by the United States Board appointed to test iron, steel, etc.

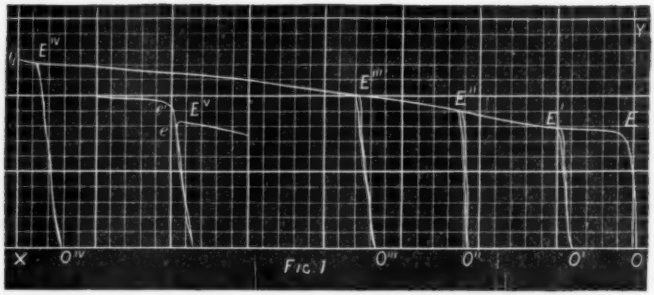


FIG. 1

of the material, and E^{I} E^{II} E^{III} E^{IV}, are the normal elastic limits corresponding to sets under loads which have strained it beyond that primitive elastic limit. In the example here illustrated, the primitive limit is found at about 20,000 pounds per square inch, or 1,400 kilograms per square centimeter, and the other points are those corresponding to loads of, respectively, 21,000, 22,500, 25,000 and 30,000 pounds on the inch, or to 1,470, 1,575, 1,750 and 2,100 kilograms on the square centimeter. The corresponding extensions, as shown on the diagram, are 1.25, 2.53, 4.50 and 6.78 per cent.

Had the stress been intermitted at either of these points any considerable period of time, there would have been observed a rise in the diagram as above stated like that shown in Fig. 1, at E^{V} the normal elastic limit e, being on subsequent test, found altered and a new limit, $é$, observed. The extent of this elevation of the limit would be the greater as the time of rest was greater, as already seen.

Thus, it is seen that a metal, once overstrained, carries, permanently, unmistakable evidence of the fact* and can be made to reveal the amount of such overstrain at any later time with a fair degree of accuracy. This evidence cannot be entirely destroyed, even by a moderate degree of annealing. Often, only annealing from a high heat, or reheating and reworking, can remove it absolutely Thus, too, a structure, broken down by causes producing overstrain in its tension members, or in its transversely loaded beams (and, probably, in compression members—although the writer is not yet fully assured of the latter), retains in every piece a register of the maximum load to which that piece has ever been subjected; and the strain-sheet of the structure, as strained at the instant of breaking down, can be thus laid down with a fair degree of certainty.

Here, then, when the work above detailed shall have been properly complemented with experimental determinations of the behavior of all the materials of general use in construction, may be found a means of tracing the overstrains which have resulted in the destruction or the injury of any iron or steel structure, and of ascertaining the cause and the method of its failure, in cases frequently happening in which they are indeterminable by any of the usual methods of investigation.

The fact of the normal variation of the elastic limit, as change of form progresses under gradually increased load, has been well established by the experiments of Hodgkinson, Clark, Mallett, and other English investigators; by Tresca, particularly, in France; by Werder and Bauschinger in Germany, and by Beardslee, the writer and others in the United States.

The exaltation of the series of normal limits so produced, still further, as shown by the writer and as seen in Fig. 1, by the intermission of strain, as at E^{V}, is also a matter of no uncertainty as to its character, although much more study is needed to determine the modifying effects of time of intermission on metals of the two great classes and of differing composition. The method above outlined

* The writer has found by subsequent tests, that transverse strain produces the same effect upon the elastic limit for tension.

of determining the extent of previous overstrain may therefore be expected to have many useful applications.

In illustration of an application of the facts thus reviewed to the determination of the causes and the method of the injury or the destruction of a structure, assume the existence of a set of conditions which is familiar to, probably, every engineer in the country who has seen much of the Howe truss, and of some other forms of bridges, as frequently built before the present generation of professional bridge builders effected a revolution in that department of engineering construction.

Suppose one of these bridges to have been built with a span of 150 feet and to have been given such proportions that, with a weight of 1,200 pounds per running foot and a load of one ton per running foot, the maximum stress on end-rods, or other members most strained, is as high as 20,000 pounds per square inch of section of metal. Suppose this bridge to have its tension members composed of a fair, but unrefined, iron, having an elastic limit at about 17,000 pounds per inch, and a tenacity of 45,000 to 48,000 pounds, and with an extensibility of about 20 per cent.

Suppose this structure to break down under a load exceeding that usually sustained in ordinary work, and the cause of the disaster to be "involved in mystery."

Suppose portions of the several tension members to be subsequently removed, and, a few days after the accident, to be carefully tested with the following results:

	Elastic Limit.	Tenacity.
Sample No. 1....	16,500	46,000
" " 2....	18,000	48,000
" " 3....	30,000	48,000
" " 4....	22,500	50,000
" " 5....	25,000	52,000
" " 6....	27,500	52,000
" " 7....	28,000	52,000
" " 8....	30,000	52,000
" " 9....	32,000	53,000
" " 10....	34,000	53,000

And that the extensibility is found to be as little as from ten to fifteen per cent.

Suppose it to be found that the tension members were straight bolts without upset ends, the threads being cut, as was once common, in such a manner that the section at the bottom of the thread is one-third less than the sectional area of the body of the bar. Suppose, finally, that the location of the tested pieces in the structure being noted, it is found that the stronger metal, having also the highest elastic limit, came from the neighborhood of the point at which the bridge gave way, and that the weakest metal and that exhibiting the lowest elastic limit came usually from points more or less remote from the break. It is not likely that in all cases the increase in the altitude of the elastic limit and the increase noted in the ultimate strength of the samples would exhibit a regular order coincident with the order of the rods as to position in the structure; since the magnitude and the arrangement of the bars would, to a certain extent, determine the relative amounts of strain thrown upon them by overloading any one part of the truss. For present purposes we may assume the order of arrangement to be thus coincident.

On examination of the figures as above given, the engineer would conclude: First, that the original apparent elastic limit of the iron used in this case must have been not far from 17,000 pounds per square inch, and that its tenacity was between 46,000 and 48,000 pounds; secondly, that this primitive elastic limit had been elevated, by subsequent loads exceeding that amount, to the higher figures given by the bars numbered from 3 to 10 inclusive; thirdly, that the ultimate strength of the material had been, in some examples given above, increased by similarly intermitted strain.

It would be concluded that the ordinary loads, such as had been carried previously to the entrance upon the bridge of that which caused its destruction, never exceeded, in their straining action, 16,500 pounds per square inch of section of tension rod at the part of the truss from which No. 1 had been taken, and that the other rods tested had carried, probably at the time of the accident, loads approximately equal to those required to strain them to the extent measured by their elastic limits at the time of testing them.

It would be concluded that the rod from which No. 10 was cut was either that most strained by the load, and therefore nearest the point of fracture of the

truss, or that it was very near that point, and it would be made the basis of comparison in further studying the case.

As this elastic limit approaches most nearly the breaking strength of the metal, we may apply the formula for the elevation of the elastic limit with time after intermitted strain which has been above given as derived from tests of a metal of very similar quality. Taking the time of intermission as one week, the extent of the increase has a probable value not far from $E' = 5 \log. 168 + 1.5$ = nearly $12\frac{1}{2}$ per cent. The magnitude of the stress upon this piece at the time of the accident was therefore 34,000 less one-ninth of that value, or about 30,000 pounds per square inch of cross-section of the bar. This corresponds to about 45,000 pounds per square inch at the bottom of the thread, and is within five per cent. of the primitive breaking strength of the iron. The bar, if broken at the screwed portion, has therefore yielded either under a dead load which was at least equal to its maximum resistance, or under a smaller load acting so suddenly as to have the effect of a real "live load." Or the slight difference here noted may be due to a flaw at the point of fracture. However that may be, it is almost certain that the body of the rod has sustained a stress of not far from 30,000 pounds per square inch.

But it is found, on further investigation, that the load on the structure at the time of the accident was but sufficient to make the maximum stress on these rods—if properly distributed—20,000 pounds per square inch at the threaded part of the piece; which piece, it has been seen, has been broken by a strain nearly double that figure. The fact is at once inferable that the load came upon these members with such suddenness as to have at least the effect of a live load (as taken in the text-books) and giving a maximum stress equal to twice that produced by the same load gradually applied, *i.e.*, the case in which the load falls, through a height equal to the extension of the piece strained by it, the resistances being assumed to increase directly as the extension up to the point of rupture,—an assumption which is approximately correct for brittle materials like hard cast iron, but quite erroneous in the case of some ductile materials, which latter sometimes give a "work of ultimate resistance," amounting to three-fourths or even five-sixths of the product of maximum resistance by the extension.

This accident was therefore caused by the entrance upon the bridge of a load capable of straining the metal to about one-half of its ultimate strength, if slowly applied, but which, in consequence of its sudden application, doubled that stress.

This sudden action may have been a consequence either of its coming upon the structure at a very high speed, or a result of the loosening of a nut, or of the breaking of a part of either the bridge floor or of one of the trucks of the train. The latter occurrence, permiting the load to fall even a very small distance, would be sufficient.

This paper is not presented as a perfectly satisfactory statement of definite facts from which absolutely reliable conclusions can be drawn. The whole subject is deserving, however, of very careful and very extended experimental investigation, and the writer has been able to obtain but a small amount of satisfactory definite information in regard to it as yet. The figures given do not exactly represent those obtained from any actual case. They do, however, fairly illustrate the limited experience of the writer, and are nearly exact for at least one case; they may serve to indicate the possible value of the cautious application of the method here outlined of studying the causes of such accidents as are considered in the hypothetical case here taken.

The same method may sometimes be used to ascertain the probable cause of a boiler explosion by determining whether the metal has been subjected to overstrain in consequence of overpressure. The causes of accidents to machinery may also be thus detected, and many other applications will suggest themselves to every engineer.

BITUMINOUS coal has been discovered near Aurora, in Nevada. It is but a few feet below the surface, and the seam is said to be about 7 ft. in thickness. If this turns out to be true, it will, in connection with the metalliferous discoveries in Nevada, be of the greatest importance.

A NEW GRAPHICAL CONSTRUCTION FOR DETERMINING THE MAXIMUM STRESSES IN THE WEB OF A BRIDGE TRUSS.

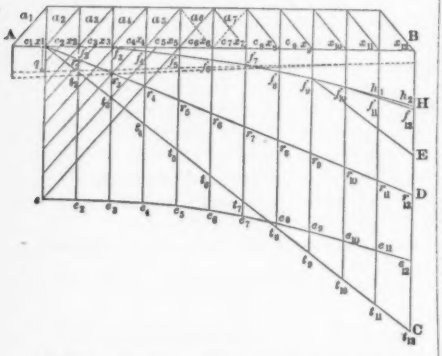
By WARD BALDWIN, University of Cincinnati.

Written for Van Nostrand's Magazine.

In Volume XVIII of this Magazine, page 26, Professor Eddy has given a graphical construction for finding the maximum stresses in a bridge truss. The determination of the maximum shearing stresses, in the article referred to, consists in successively subtracting the difference between the maximum shearing stresses on two consecutive joints from the total reaction of the pier when the live load covers the entire bridge. As thus constructed the errors are cumulative.

It is the object of this paper to propose a construction which will determine each of the maximum shearing stresses in a truss independently, and not as the sum or difference of several magnitudes. This, it is believed, permits of greater accuracy, than any construction heretofore proposed.

Suppose the bridge to be a through bridge. Let the live load consist of one or more locomotives which, to begin with, stand at n'' of the joints x_1 x_2, etc., at the left hand end of the truss, together with a uniform train of cars which covers the remaining joints.



Let s_1, s_2, etc., be the maximum shearing stresses at the joints x_1, x_2, etc.

w=the dead load on one joint.

w'=the load, due to the train of cars, on one joint.

$(w'+w'')$=the load, due to the engines, on one joint.

n=the number of the joint considered, reckoning from A.

n'=the number of panels in the truss.

n''=the number of joints loaded with locomotives.

$m=n'-n''$.

Now in the figure lay off $ex_1=r$, the reaction at the pier A when the live load covers the entire bridge in the manner above stated. The value of $Ex_1=r$ can be readily found by the principle of the lever. When the train moves off to the right, so that no live load rests on the joint x_1 and the locomotives stand on the n'' joints x_2, x_3, &c., then the reaction of the pier A has been diminished by the amount $\frac{n'-1}{n'}(w'+w'')$, and it has been increased by the amount $\frac{n'-(n''+1)}{n'}$, w''; as was proven in the article before referred to. Therefore the reaction of the pier A has been diminished by the difference of these quantities, that is to say, by the amount $\frac{1}{n'}[(n'-1)w'+n''w'']$.

Now the maximum shear at the joint x_2 is this reaction diminished by the load at the joint x_1. Therefore the maximum shear at the joint x_2 is

$$s_2=r-w-\frac{1}{n'}[(n'-1)w'+n''w'']$$

By similar reasoning the maximum shearing stress at the joint x_3 is found to be

$$S_3=r-w-\frac{1}{n'}[(n'-1)w'+n''w''] \\ -w-\frac{1}{n'}[(n'-2)w'+n''w''].$$

Successive maximum shears may be computed in a similar manner, and in general the *shear* at the joint x_n is

$$s_n=r-w-\frac{1}{n'}[(n'-1)w'+n''w'']-w-$$

$$\frac{1}{n'}[(n'-2)w'+n''w'']-\ldots$$

$$-w-\frac{1}{n'}[(n'-(n-1)]w'+n''w''],$$

provided n is less than $n'-(n''-1)=m+1$, as will be shown presently; and s_n has a *maximum* value provided $n<\frac{n'}{2}+1$.

Now if for convenience we let $q=[w+\frac{1}{n'}\ (n'-1)w'+n''w'')\ ]$, then the values of the maximum shearing stresses may be expressed as follows:

$s_1=r$

$s_2=r-q.$

$s_3=r-q-q+\frac{w'}{n'}=r-\left(2q-\frac{w'}{n'}\right).$

$s_4=r-q-q+\frac{w'}{n'}-q+\frac{2w'}{n'}=r-\left(3q-\frac{3w'}{n'}\right)$

and in general it is evident that

$$s_n=r-\left\{(n-1)\ q-\frac{1+2+3+\ldots+(n-2)}{n'}w'\right\}=r-\left\{(n-1)q-\frac{(n-1)(n-2)}{2n'}w'\right\}(a)$$

Now in the figure lay off $BC=(n'-1)q$ and join cx_1 by the line t_1, t_2, etc. At x_2, x_3, etc., lay off $x_2\ f_2=\frac{w'}{n'}$, $x_4\ f_4=\frac{3w'}{n'}$ $x_5 f_5=\frac{6w'}{n'}$, etc., and in general, $x_n\ f_n=\frac{(n-1)(n-2)}{2n'}w'$. Then the ordinates f_2 t_2, f_3 t_3, f_4 t_4, etc., represent the amounts to be subtracted from r to obtain the maximum shearing stresses at the joints x_2, x_3, x_4, etc. For these ordinates are equal to q, $\left\{2q-\frac{w'}{n'}\right\}$, $\left\{3q-\frac{3w'}{n'}\right\}$, etc., respectively; and these amounts must be taken from r to obtain the maximum shearing stresses at the joints x_2, x_3, x_4, etc., as is shown by formula (a). Lay off these ordinates on $ex_1=r$, measuring from e. Then the distances from x_1 to the points thus found represent the maximum shearing stresses at the joints x_2, x_3, etc.

From e and the points thus found draw lines parallel to the inclined members of the web, viz., $a_1\ c_1$, $a_2\ c_2$, etc., terminating in the horizontal through x_1. Then these lines represent the maximum stress on the members $a_1\ c_1$, $a_2\ c_2$, etc.

From the points f_1, f_2, f_3, etc., lay off the vertical ordinates $f_1e=r$, $f_2e_2=r$, $f_3\ e_3=r$, etc. Then the ordinates $t_1\ e_1$, $t_2\ e_2$, $t_3\ e_3$, etc., represent the maximum shearing stresses at the joints x_1, x_2, x_3 etc. Then the point G shows where the sign of the shear changes, and therefore how far counters are needed.

On BC lay off $DC=(n'-1)w$ and join Dx_1 by the line r_1, r_2, etc. Then the ordinates $r_1\ e_1$, $r_2\ e_2$, $r_3\ e_3$, etc., represent the reactions of the pier A as the train moves towards the right and the live load is removed from one joint after another; for $r_1\ t_1=0$, $r_2\ t_2=w$, $r_3\ t_3=2w$, etc. . . . But 0, w, $2w$, $3w$, etc., are the amounts which must be taken from the reactions of the pier A to obtain the maximum shearing stresses at the joints x_1, x_2, x_3, etc.

Now when the train has moved so far to the right that the live load rests on only n'' joints, the live load consists of engines alone; and, reckoning from A, the number of the first joint loaded with the live load is $(n'-n'')=m$. To find the shearing stress at the next joint to the right, that is at the joint x_{m+1}, the live load is moved off of the joint x_m, and the reaction of the pier A is thus diminished by the amount $\frac{n''}{n'}(w'+w'')$. As the engine load on the joint next to B is at the same time moved to the pier B, the reaction of A is not affected by the additional load on B. Therefore the shearing stress at the joint x_{m+1} is less than the shearing stress at the joint x_m by an amount equal to $w+\frac{n''}{n'}\ (w'+w'')$. By similar reasoning we can also at once show that the shearing stress at the joint x_{m+2} is less than the shearing stress at the joint x_{m+1} by an amount equal to $w+\frac{n''-1}{n'}(w'+w'')$, etc.

Now, for convenience, let the ordinate f_mt_m equal p, and also let $w+\frac{n''}{n'}(w'+w'')$ equal h, then the shearing stresses at the joints x_{m+1}, x_{m+2}, are evidently,

$s_{m+1}=r-(p+h)$

$s_{m+2}=r-(p+[2h-\frac{1}{n'}(w'+w'')])$

$s_{m+3}=r-(p+[3h-\frac{3}{n'}(w'+w'')])$, etc.

which shearing stresses have evidently a maximum value, provided the end of the live load has not yet passed the center of the bridge. This may be the case if the span is short, or if the value of n'' is great. Finally, at the joint n', the shearing stress is

$$s_{n'}=r-(p+[n''h-\frac{1+2+3+....+(n''-1)}{n'}(w'+w'')]$$
$$=r-(p[n''h-\frac{n''(n''-1)}{2n'}(w+w)]);$$

and this is the reaction of the pier B due to the dead load.

In the figure from the point f_m draw a line to E parallel to x_1c. From E lay off $EH=n''h$, and join f_m to H. From the points h_1, h_2, etc., lay off the ordinates

$$h_1 f_{m+2}=\frac{1}{n'}(w'+w''),\ h_2 f_{m+2}=\frac{3}{n'}(w'+w''),\text{ etc.}$$

Then will the ordinates f_{m+1}, t_{m+1}, f_{m+2}, t_{m+2}, etc., represent the amounts to be taken from r to obtain the shearing stresses at the joints x_{m+1}, x_{m+2}, etc.; for these ordinates are equal to $p+h$, $p+2h-\frac{1}{n'}(w'+w'')$, etc. From the points f thus found lay off the distances $f_{m+1}\ e_{m+1}=r$, $f_{m+2}\ e_{m+2}+r$, etc.; then $t_{m+1}\ e_{m+1}$, $t_{m+2}\ e_{m+2}$, etc., represent the shearing stresses on the joints x_{m+1}, x_{m+2}, etc.

The ordinate $e_{n'}\ t_{n'}$ represents the shear at B when the live load has passed off of the bridge; therefore $e_{n'}\ t_{n'}$ is the reaction of B due to the dead load. The ordinate $e_{n'}r_{n'}$ represents the reaction of A when the live load has left the bridge, as is shown above, and is, therefore, the reaction at A due to the dead load. Hence, evidently, $e_{n'}$ should be equidistant from $t_{n'}$ and $r_{n'}$.

If, instead of an unsymmetrically distributed live load, a uniform live load covers the bridge and moves off to the right, the construction used to determine the shearing stresses after the live load consisted entirely of engines is applicable to the whole bridge, and p becomes zero.

If the bridge is a deck bridge instead of a through bridge, the ordinates $t_1\ e_1$, $t_2\ e_2$, $t_3\ e_3$, etc., represent the maximum stresses on the ties c_1a_2, c_2a_3, etc., instead of on the ties c_2a_2, c_3a_3, etc. But the maximum stresses on the inclined members are the same in a deck as in a through bridge, and therefore the number of counters is the same for both forms of bridge.

The construction proposed may be briefly stated as follows:

To determine the maximum shearing stresses, lay off $BC=(n'-1)\ [w+\frac{1}{n'}(n'-1)\ w'+n''w'')]=(n'-1)q$, and draw the line x_1C; at the joints x_2, x_3, etc., lay off distances equal to 0, $\frac{w'}{n'}$, $\frac{3w'}{n'}$ etc; then the ordinates between the points thus found and the line $x_1\ C$ are to be subtracted from $x_1e=r$, to obtain the maximum shearing stresses at the joints x_2, x_3, x_4, etc.

q may be found graphically by the construction given by Professor Eddy, as is shown in the figure, and the line $x_1\ t_2$ be prolonged to c. Then BC will equal $(n'-1)q$. The quantities 0, $\frac{w'}{n'}$, $\frac{3w'}{n'}$, $\frac{6w'}{n'}$, etc., are the terms of a regular series whose first differences are $\frac{1}{n'}\cdot w'$, $\frac{2}{n'}.w'$, $\frac{3}{n'}.w'$, etc., in regular numerical order, and they may therefore be calculated mentally and laid off at once.

Suppose, for example, that in the figure the scale of lengths is 30 feet to an inch, and the scale of weights is 40 tons to an inch. Then

$ex_1=r=73.5$ tons,
$w=6$ tons,
$w'=6$ tons,
$w''=3$ tons,
$n'=12$, $n''=3$ and $m=9$.

Also $BC=(n'-1)q=11\times[6+\frac{1}{12}(66+9)]$
$=11\times12.25$ tons$=134.75$ tons,

$x_1f_1=0$, $x_2f_2=0$, $x_3f_3=0.5$ ton, $x_4f_4=1.5$ tons, $x_5f_5=3$ tons, $x_6f_6=5$ tons.

And the maximum shears are, by measurement,

$S_1=73.5$ tons, $S_2=61.25$ tons, $S_3=49.5$ tons, $S_4=38.25$ tons, $S_5=27.5$ tons.

The position of the point G shows that only one counter is needed on each side of the center. It is the practice to put in one or two more counters on each side of the center than is necessary for a static load.

ON THE EFFECT OF RIVER IMPROVEMENT WORKS.*

By JAMES DILLON, Mem. Inst. C.E.I.

From "Engineering."

The great floods, due to the unusual rainfall of late years, have caused so much damage and misery in different countries that the subject is at present engaging the serious attention of scientific men.

It is known that in the great majority of cases the discharging capacity of the rivers and their tributaries is insufficient to carry off the flood waters without overflowing their banks, due in a measure to the existence of numerous hard gravel and rock shoals, mill-dams, badly constructed bridges, and insufficient sectional areas, &c. To remove these defects it has hitherto been the practice to deal with a system of rivers, or at least with the main and principal tributaries belonging to one catchment basin (by catchment basin is meant the entire district of country unwatered by a river and its tributaries, it may, therefore, embrace mountains or lakes), and to endeavor to borrow money from Government or other parties to carry out the works necessary for the removal of the obstructions above referred to, commencing upon the lower reaches of the river system and carrying the works upwards. Many useful works have been carried out in different countries, particularly in Ireland, where the progress of the arterial drainage works, under 5 and 6 Vict., c. 39, up to July 31, 1863, was as follows: The total amount of loans obtained and expended under the direction of Government, previous to 1863, on river or arterial drainage works, equaled £2,390,612 (exclusive of the coast of Shannon), and the repayments in respect thereof, including interest, amounted on March 31, 1878, to £1,341,522. This money was expended on various river works extending over not less than 2000 miles of rivers and tributaries, the works being designed so as to convey the flood waters from 120 different catchment basins of an aggregate area of 6,358,358 statute acres. The object of these works was to relieve 266,736 statute acres of good land, at an average cost of £7 per acre, adjoining the 2000 miles of river banks and shores of lakes, from the injurious effects of flood waters. Particular attention should be paid to the fact that the ground covered with water was only $4\frac{1}{3}$ per cent., or about $\frac{1}{24}$ of the entire catchment basins, as this will have to be dwelt upon hereafter. The above works were executed by Drainage Commissioners appointed under 5 and 6 Vict., c. 89, and no doubt conferred great benefits on the country, but both the country and the Government concurred in thinking the outlay was too great, and further action as regards new works was suspended, under the 5 and 6 Vict. Then, in 1863, owing to previous agitation in and out of Parliament, the Government sanctioned a general drainage act being passed for Ireland authorizing private parties to form drainage districts (see Act 26 and 27 Vict. c. 88, and Acts passed amending the same), provided that two-thirds of the injured land in value are owned by parties assenting to the project, and if the two-thirds petition, the Government will grant the necessary money to to carry out the works, if satisfied with the financial prospects of the undertaking.

Progress of arterial drainage works in Ireland, under 26 and 27 Vict., c. 88, from 1863, to July 31, 1878, was as follows: Under this act the works for 37 districts have been sanctioned and are now nearly completed. Their effect has been to drain and free from floods not less than 71,000 statute acres, at a cost of £389,000, equal to an average outlay of not less than £5 9s. per acre as compared with £7 per acre under the 5th and 6th Vict. Notwithstanding that the above results as regards Ireland are so far satisfactory, still it is a fact that year by year such works are becoming more difficult of accomplishment, owing to the impossibility of adjusting the conflicting interests of the upland and lowland proprietors. If the lowland proprietors promote a scheme for the improvement of their larger and consequently more costly

* Read before Section G of the British Association: Dublin meeting.

sections of their rivers, they generally try to tax the upland proprietors for works that can confer no benefit upon them, while if the upland proprietors try to improve their smaller and less costly rivers they are opposed by the lowland proprietors, who contend that their floods are made worse by the drainage of the uplands, &c. The extent to which these supposed conflicting interests interfere with the carrying out of such works may be judged from the fact that the Board of Public Works in Ireland, in their report for 1877-78, announce that from Ireland last year there was only one application for a new drainage district, so that unless subsequent legislation proves more successful, there will be few if any useful works of this class carried out when those already sanctioned are completed.

It has occurred to the author, who has been entrusted with the expenditure of some £157,000 on rivers, or nearly one-half of the money expended on such works since 1863, under 26 and 27 Vict., that the principal objection to the extension of such works can be proved to be unfounded, viz., that the extension of arterial drainage or river works up country increases the volume of river floods sent down from the drained districts, to the injury of the low-land proprietors.

The following are the particulars of some arterial drainage works lately carried out under the direction of the author, which had not the effect of increasing the flood discharge. They are known as the Upper Inny Drainage Works, and were commenced in 1870. These works extend over 82 miles of rivers and tributaries, the catchment basin or area of country discharging its waters into this system of rivers extends over an area of 273 square miles, and its centre is situated about 53 miles to the west of Dublin, at a level of 211 feet above the sea, the rock formation being limestone.

The whole of the river works were designed so as to carry off the flood waters about 4 feet below the surface of land, which formerly saturated and covered with water 12,260 statute acres of land, equal to 7 per cent. of the catchment basin. During the progress of the works it was necessary to carry out extensive rock, gravel, and other excavations, and to rebuild some 60 bridges, the total cost of which will amount to some £60,000. The works under the author's charge were commenced near Lough Iron, at the point where the Lower Inny Works, carried out under the care of the Drainage Commissioners of Ireland, were suspended on account of their excessive cost and want of funds, &c., to proceed further up country. Previous to the commencement of the Upper Inny Drainage Works, the average summer discharge in the river from the upper district amounted to .0689 per acre per minute, and the average flood discharge to .4896 per acre per minute. After the execution of the works the average summer discharge at the same place amounted to .0827 per acre per minute, and the flood discharge to .4827 per acre per minute. Similar results have been obtained by the author in other districts, and it may be added that the Earl of Ross and Mr. Forsyth, late engineer to the Commissioners of Public Works of Ireland, both concur in his views on the subject.

It has been shown that in the above district, while the total area of the catchment basin amounted to 273 square miles or 175,000 acres, the ground covered with water along the 82 miles of rivers and tributaries amounted to only 12,250 acres, or about 7 per cent. of the whole catchment basin, and, further, that the average breadth of the flooded land equaled 75 statute perches, or 1237 feet. This is not an exceptional case, for it is already stated in this paper that in the other districts already executed, 120 in number, the total amount of flood water along the river flats covered only $4\frac{1}{2}$ per cent. of the catchment basin. From this it follows that there is not less than 93 per cent. of the Upper Inny district situated above flood level, so that 93 per cent. of the floods due to the rainfall falling upon the entire district could flow just as freely on to the 7 per cent. flooded lands along the river banks before the execution of the works as they could after the execution of said works.

It must not be forgotten that the flooded 7 per cent. is always more or less saturated with water, particularly in winter, and that when so saturated it can hold no additional water except the flood water flowing over its surface.

It is believed by many that this flood

water remains stationary, but this cannot be, inasmuch as the river valley has always (unless in very exceptional cases) a very perceptible fall, otherwise sufficient velocity would not have been given to the waters of the country to have cut any kind of river through its valley. From this it follows that whether the river banks are or are not flooded, the whole of the flood waters in the river valley are in motion until they rise to what is known as the maximum flood level. At this level the waters will only remain so long, as the maximum yield from the maximum rainfall in the district can keep them up to it. So that as long as the flood level remains stationary no further ponding of the flood waters can take place, and therefore the maximum flood due to the maximum rainfall will flow along the river valley for days and weeks without increasing in height, spreading over the country where the banks are low, and confining itself to the river where there are cliffs or high banks, but not exceeding the maximum flood level even at these points. If then the flood waters do not increase in height the whole flood discharge must be passing out of the district, and if this can occur before a river is enlarged or improved, enlarging a river channel can neither increase the rainfall nor the flood yield from same sent down to lowland proprietors.

Having shown that the sheets of flood waters spreading over a river valley are in constant motion, it will be observed that just as they commenced to rise because they could not get away before the flood waters came pouring into the river valley from the more distant portions of the catchment basin, so after the maximum floods have ceased to flow from the last named places into the main river valley these sheets of flood water fall in level, and in doing so increase the flood discharges towards the close of the wet season by the volume of water covering the river valley which would not have been there had the district been drained. It will be said if the effect of the arterial drainage works is to prevent the accumulation of large sheets of flood waters in a river valley, then the floods must be increased by the passing away of these waters.

The author believes this to be a mistake. He has already shown that the flooded ground seldom averages 7 per cent. of the catchment basins, and in the Inny district above referred to it equaled an average breadth of 1537 feet or 7 per cent. If then a number of tributary rivers with catchment basins some 2 miles in breadth, and some 8 or 10 miles in length, branch off at nearly right angles to the main river, along which this 7 per cent. flooded land exists; then if you divide these lateral catchment basins into 100 parts, allowing the 7 parts near the river to be flooded, it will be evident that the maximum flood due to the maximum rainfall on the seven parts, or 7 per cent. at the junction of the tributaries with the main river, will have passed away into the main river before the maximum floods from the second, third, or tenth miles, &c., could reach the last named junctions, were the rivers not dammed up with shoals, &c., so that the time required to allow of the river valleys being covered with water before the execution of the works would, if properly utilized, be more than sufficient to allow of said water passing down a properly constructed river channel before the maximum floods could reach the main river from the second, third, or tenth mile back from the main river. If this holds good in narrow tributary catchment basins, so will it be applicable to all forms of catchment basins, no matter what their direction with regard to the main channel. The author believes, then, that the effect of arterial drainage works is to enable the floods from the fractional 4, 7 or 8 per cent. flooded lands near the main arteries to pass off after execution of works many hours or days sooner, according to the magnitude and length of the rainfall and district than before execution of works; and that by securing a longer interval of time for the discharge of a flood of given magnitude, arterial drainage works cannot increase the maximum flood discharges of a district.

As this view of the case is confirmed by the author's observations, he invites discussion in order to test its accuracy. When once it is established that the floods in a river valley are not increased by the enlargement or improvement of either an upper or lower section of the river passing through said valley, the author

believes that the public and the Government would find it more practical to deal with the improvement of rivers in the following way:

Whenever any considerable portion of a country is flooded by the overflow of a river or its tributaries, and the parties injuriously affected are desirous of applying to Government through the Commissioners of Public Works in England, Ireland, or elsewhere, for a loan to improve their land, they should be required to furnish a section of the rivers to be improved, taking care to extend the sections down the river until a sufficient outfall is obtained for the successful carrying out of the proposed works. Should the Board of Works report in favor of the project, the treasury could advance the necessary funds, thus enabling useful works to be carried out under the superintendance of drainage boards acquainted with the localities with which their interests are connected, instead of losing many years in endeavoring to embrace all the districts or tributary districts in one large, costly and unmanageable scheme. By this method the works could be commenced in divisions corresponding to the natural sub-outfalls of the country, commencing at the fall nearest to or furthest from the sea.

Should this method be sanctioned by Government on any large scale, now that it is proposed to grant loans for river works, on a moiety of the proprietors assenting to the project instead of requiring two-thirds, as formerly, a great impetus would be given to the extension of such works, conferring great benefits upon the country by increasing the value of land, and giving at the same time additional employment, and circulating large sums of money among the working classes in the agricultural districts. Although the facts thus briefly set forth in this paper are now publicly brought forward by the author for the first time, still, in the case of the great Barrow river scheme which embraces a country of 625 square miles, he has succeeded in overcoming hostile opposition (based upon increased flooding) to its being executed in divisions instead of in one vast unmanageable whole. Of this work two divisions have already been sanctioned by Parliament, and are now nearly completed.

The object of the author in bringing forward these facts is that the practicability of dealing with large river systems in divisions, instead of in one whole, may become more universally known and acted upon.

ON THE MANUFACTURE OF ARTIFICIAL FUEL.

BY E. F. LOISEAU.

A Paper read before the American Institute of Mining Engineers.

UNTIL June, 1868, it had not been attempted, either in this country or abroad, to manufacture, by mechanical means, from anthracite coal-dust, artificial fuel for domestic use. Several attempts had been made to utilize coal-waste by converting it into a fuel for manufacturing purposes, but none of the processes were original, and they were merely applications of the well-known European processes and machinery, slightly modified by American ingenuity and mechanical skill. With one exception all those attempts have been failures.

The great difficulty in the application of European processes and machinery has always been the limited production and the excessive cost of the manufactured product, as compared with the cost of mining and preparing the ordinary anthracite coal for the market.

The only serious and intelligent attempt to manufacture, on a large scale, artificial fuel for manufacturing purposes has been made by the Anthracite Fuel Company, whose works are erected at Fort Ewen, near Rondout, New York. This company, organized under the auspices of the Delaware and Hudson Canal Company, had to go through the usual course of difficulties, breakages and disappointments, which seem to be the lot of every new industry. Thanks, however, to the energy and perseverence of

Mr. L. L. Crounsse, a gentleman of means, from Washington, D. C., the enterprise succeeded, and it is to-day established on a permanent basis.

In order to increase the production, and to reduce its cost, the Anthracite Fuel Company was compelled to change most of its plant, and to erect more powerful machinery, producing lumps of a larger size, almost twice the size of the lumps made previously by the same company. This increase in the size of the lumps has been resorted to in Europe as well as in this country, in order to increase the production; but the lumps, being large, require a strong draft for their combustion, and consequently the use of artificial fuel has been confined almost exclusively to steamers and locomotives.

In order to manufacture a fuel which could be used in all kinds of furnaces, it was evident that the lumps should not exceed a certain size, and machines for this purpose were invented by Mr. Revollier-Bietrix, of St. Etienne, France, and by Messrs. Mazeline and Couillard, of Havre; but the production of these machines, in 24 hours, did not exceed 48 gross tons, in lumps weighing, each, one kilogram, 250 grams. No better results have been obtained in Europe to this day, and no smaller lumps have been manufactured there.

The compressing machines, above referred to, are constructed on the principle of Gard's brick machines in this country. Circular horizontal tables, containing either stationary or movable molds, revolve under a pug mill, in the center of which is a vertical shaft, with knives placed at an angle. These knives force the materials into the molds. The bottom of the molds is formed by followers, fitting exactly, which travel on an inclined plane under the molding table, gradually compressing the materials, and finally expelling the brick-shaped lumps, which are afterwards removed by hand, or pushed by a scraper on a conveying belt.

The problem, therefore, was to obtain a large production in lumps of a small size, and my efforts for the last ten years have been directed toward the solution of that problem.

I devised and designed, to the best of my ability, several machines which my experience had told me were best adapted to the continuous and automatic production of lumps of a small size, the main machine being the press. I had previously made a good many experiments, on a small scale, which had demonstrated beyond a doubt the practicability of the process. A good many of our members will remember to have witnessed in Mauch Chunk, in 1874, the manufacture of the fuel by a small machine, which was the embryo of the large one erected at Port Richmond. As is usually the case, the large machine did not work as well as the small one; it had to be modified several times, according to what practical experience demonstrated to be an absolute necessity. One modification suggested another, until at last, in spite of all the prophecies to the contrary, I succeeded in getting the press to work in a very satisfactory way. The production is 137½ tons in 10 hours, the lumps weighing but two ounces each.

I will give here a brief description of the moulding press:

Two rollers, each 30 inches in diameter, and 36 inches in length, contain on their surface semi-oval cavities, connected together by small channels, which allow the escape of air and excess of material, each cavity or recess communicating by four of those channels with the surrounding ones. These cavities extend in close proximity to each other, in regular rows over the whole length of the rollers, the recesses of every other row being intermediately between those of the adjoining row, in the nature of the cells of a honeycomb, so that small metallic contact surfaces are formed, and the entire surface of the roller is utilized for compressing the composition into lumps of an egg-shaped form. The shafts of the rollers are cast solid with the rollers, and they are 10½ inches in diameter. Each roller weighs over a ton. On top of these is a hopper, 36 inches long and 30 inches wide, in which the materials to be compressed are discharged from the mixer. In this hopper a series of knives, screwed to a small horizontal shaft, revolve rapidly, and keep the materials in a granulated state.

When the materials to be compressed happened to contain too much water, which was often the case, the mixture was very plastic, and the lumps were spongy and unfit for use. When the

mixture contained the required amount of water, the rollers would spring, and would deliver nothing but half-lumps. Every means was resorted to in order to prevent the springing of the rollers, and to mold complete lumps. All sorts of contrivances, suggested by able mechanical engineers, were tried, without success. Considerable time was required, and a large amount of money was expended to obtain the desired result. The task had been given up by a good many as a hopeless one, still I persevered. I had observed that, when the hopper was almost empty, the shaking of the rollers stopped, and the half-lumps of the last rows remained in the molds, instead of being discharged on the conveyor below. I concluded from this fact, that the springing of the rollers was produced by an excess of material above the compressing point, and that if I could regulate the quantity of material a little above that point, the springing of the rollers would cease, and perfect lumps would be produced. The thought was a happy one. I devised several attachments to regulate the delivery of the materials on both rollers, with only partial success, until at last I concluded to muffle one roller entirely with sheet iron, and to deliver the materials on the other one. In the centre, above the point of contact of the two rollers, I placed an iron gate, 36 inches long, 3 inches thick, and 3 inches wide, guided at both ends inside of the hopper, and working up and down along those guides, by means of two long bolts, threaded at one end, passed through a stationary nut, fastened in a wooden cross-piece above the hopper and worked by small hand-wheels. By reducing or increasing the space between the bottom of the gate and the roller, more or less material was carried away by that roller. At the point of contact between the rollers, the materials which have been delivered on one roller are pushed into the cavities of the other one, and perfect lumps are formed and discharged on the conveyor below. The difficulty is entirely overcome, and the press has worked well ever since.

The coal dust accumulated in the yard is on swampy ground; the tide-water comes up to the middle of the lot, and the capillary attraction draws the water the coal-pile up as high as seven feet. During dry weather we obtained from the top of the pile coal sufficiently dry, but when it rained the coal dust was so wet that it clogged in the screen, in the chutes under the chain elevators, in the coal pocket and in the distributor. This was remedied by erecting a gravel-drying apparatus, composed of two drums, 18 feet in length and 36 inches in diameter, placed on an incline and heated underneath. The drums revolve slowly; the coal dust, as it comes from the yard, is fed at one end of each drum; it travels the entire length of the drums in five minutes, while being kept stirred by stationary lifters, fastened inside of the drums, and it is finally screened and discharged at the other end perfectly dried.

In the drying oven we had the next trouble. The first plan consisted in carrying the molded lumps through the oven in 40 minutes, on five endless wire-cloth belts, placed underneath each other, and geared together, so as to travel in opposite directions. The lumps falling from the rollers on the upper belt were conveyed into the oven at the speed of 12 feet in one minute, traveling the whole length of the oven and falling from one belt to another, until they emerged from the oven on the lower belt, to be discharged therefrom into the waterproofing machine.

When the five wire-cloth belts were loaded, the oven contained about six tons of coal. Under the weight of the fuel the belts would stretch, sag, and drop the greatest part of the lumps on the bottom of the oven, where they broke to pieces. The belts were changed several times, and replaced by others of smaller mesh and stronger wire; additional rollers were placed under the wire-cloth to stop the sagging as much as possible, but the belts would stretch in spite of all, and the use of wire-cloth as conveyors had to be abandoned.

It was also ascertained that the fuel was imperfectly dried, and that the contraction of the clay, used as a cement, could not take place when the lumps remained only 40 minutes in the oven. The solidity of the lumps was found to depend entirely upon the length of time during which they remained in the oven, and the following tests demonstrated this fact to a certainty:

Three lumps which had been in the

oven during 40 minutes supported a weight of 99 pounds before being crushed.

Three lumps which remained in the oven one hour and ten minutes stood a weight of 148 pounds before being crushed.

Three lumps which had remained in the oven during six hours stood a weight of 371 pounds before giving way.

Each one of these lumps came from the same mixer, and contained the same materials, and in the same proportions.

The problem then was not only to modify the oven so that it would hold sufficient fuel during six hours, but to modify it in such a way that the fuel could be discharged by its own gravity, when sufficiently baked. To do this seemed an insuperable difficulty. I studied for weeks one plan after another, until at last I conceived one which I thought would answer the purpose. I submitted the plan to competent authority, and it was approved as a feasible and practicable one.

The plan consisted in doing entirely away with wire-cloth, in suppressing the four lower conveyors, and in using for the top conveyor sections of sheet iron bolted to bridge links of malleable iron, placed at regular intervals, in three endless link chains running in grooves and moved by toothed wheels. The fuel was to be removed from this top conveyor by gates thrown slantingly across it, and it would slide down iron chutes, forming a spiral, upon bars of wrought iron set at an angle across the oven, and resting upon cast-iron racks, placed at the lowest point, 18 inches above the flue. Through those bars and through the mass of the fuel, the hot air was to pass and dry the fuel.

When the fuel was baked it was to be discharged by its own gravity, and through a series of gates, on an outside conveyor, placed alongside the oven, and made of sections of sheet iron, bolted to link chains like the top conveyor. This outside conveyor was to dump the fuel into an elevator, and from this elevator the lumps were to be delivered into the waterproofing machine.

The alterations described above were made, and the whole oven became in this way a kind of coal-bin, holding very near one hundred tons of fuel.

When the oven, modified as stated, was tried for the first time, it contained nearly one hundred tons of good lumps. It was heated to about 300° Fahrenheit, and in about four hours the whole mass of fuel was on fire. It required ten men working two days and one night to extinguish the fire. The fuel was entirely spoiled, but no injury was done to the walls of the oven, or to the inside fixtures of the same. In order to avoid such an accident in the future, the cast-iron flues were covered with loose bricks. Three times in succession the oven was again filled, heated, and when it was supposed that the lumps were sufficiently baked, the discharge gates were opened, and the fuel was found to be as moist as when it entered the oven.

The oven was allowed to cool, and was carefully examined by Dr. Charles M. Cresson, of this city, and it was ascertained by him that the openings for the admission of air, and for the escape of the evaporated moisture were much too small. The fuel, as it seems, had simply been submitted to a steam bath, instead of being baked, and the defect could be easily remedied, according to Dr. Cresson's opinion, by a false sheet-iron bottom, which would bring the air in close contact with the iron flues, and at the same time prevent the fuel from catching fire by radiation from the flues. Dr. Cresson advised larger openings for the admission of air and for the outlet of moisture. The sizes of those openings have been carefully calculated, and there is no doubt that when these alterations shall have been made, the working of the oven will be as satisfactory as that of the balance of the machinery.

The waterproofing process has been tried several times, and has been found to work well. Instead of condensing the vapors of the benzine, as was at first intended, we were compelled, in order to avoid accidents, to remove them by a suction fan. These vapors pass through a system of pipes; they are here mixed with twenty times their volume of atmospheric air, so as to render them innocuous, and they are then expelled above the roof of the building.

It must not be forgotten that the process applied, and the machines used, were entirely novel, and considering all the difficulties in the way of success, the

results obtained have been very satisfactory.

The large amount of money expended, the many disappointments which have occurred, and, above all, the depressed condition of the coal trade during the last two years, have discouraged some of our stockholders, and we have thus been placed in a financial condition which has prevented the completion of the experiment. In a few days, however, the financial difficulties will also be entirely overcome, a new company will be reorganized, and I hope that in a few weeks the works will be in successful operation, and the fuel will be in the market.

ON THE DISCHARGE OF SEWAGE INTO TIDAL RIVERS.*

By H. LAW.

From "Engineering."

The present paper is intended as a contribution towards the important subject of the treatment and conservation of rivers.

Mr. William Hope, whose name has long been before the public in connection with this subject, in a recent letter addressed to *Engineering*, makes the startling assertion that the pollution of the river Thames by the sewage is cumulative; that is to say, in other words, that there is no fixed limit to the percentage of sewage pollution, which must go on in an ever-increasing ratio.

It is, therefore, of great importance to examine this matter with some care, in order to determine with exactness what are the actual condition of tidal rivers into which certain quantities of polluting matter are discharged.

Now, a tidal river may be looked upon as a reservoir of a very elongated form, subject to the following conditions, namely:

1. That it is supplied with water of three different qualities, from three different sources, that is to say:

The water constantly draining off of the surface of the basin forming the watershed of the river, and that derived from the land springs which find vent in its bed; this we will designate river water.

The water entering the mouth of the river from the sea, under tidal influence, which we will disgtinguish as sea water.

The polluted water discharged from the sewers, which we will term sewage.

2. That the actual and relative quantities of these are not constant, but vary within certain limits.

3. That the supply of sea water is not constant, but intermittent, being poured into the reservoir for a certain number of hours, and then, for a certain period, the reservoir being allowed to discharge a proportion of its contents.

Now in the actual state of things the river water may, and usually does, enter the channel of the river by tributary streams at various points, and the sewage may be discharged at many different places, while the quantity of both the river water and the sewage will vary according to the amount of the rainfall and other circumstances; but in inquiring as to the ultimate degree of pollution of the river, we may simplify the question under consideration, without in any way invalidating the result, by assuming that the whole of the river water enters by the upper extremity of the channel, or elongated reservoir, and that its flow is uniform and equal to the mean quantity taken over a lengthened period; further, that the sewage is all collected and discharged into the channel or reservoir at some intermediate point, and that its flow is also uniform, and equal to the mean quantity; furthermore, that the sea water is poured in at the lower extremity of the channel at regular intervals for a certain period, and that the only discharge of the contents of the channel or reservoir is at its lower extremity, also for a definite time, and in such a manner that for a certain period in every twelve hours the contents of the reservoir would be accumulating, and, as a consequence, the level of its surface rising, and that

* Read before Section G of the British Association: Dublin meeting.

then for a certain time, the contents would be diminishing and the level of its surface falling.

Now, the subject of our inquiry is, what, under the conditions assumed above, will be the mean or average composition of the water contained in the reservoir or river?

In order to obtain a practical result, let us investigate this question, adopting the mean values for the several quantities which apply in the case of the river Thames.

First, then, as to the extent and capacity of the reservoir. The tidal portion of the River Thames extends from Yantlet Creek, where the jurisdiction of the Conservators commences, to Teddington Lock, a total distance of 318,160 feet, or about 60¼ miles; its breadth varies from about 200 feet to 22,800 feet, or about 4½ miles at its mouth. Its superficial area at high water is 58,182,380 square feet above London Bridge, and 1,054,362,660 square feet below the same, making a total of 1,112,545,040 square feet, or about 40 square miles. At low water the superficial area above London Bridge is 38,807,800 square feet, and that below the same 681,786,610 square feet, making a total of 720,594,410 square feet, or nearly 26 square miles.

The mean range of the tide at the mouth, that is, at Yantlet Creek, is 14 feet; at London Bridge 17 feet 4 inches, and at Teddington Lock 3 feet.

The mean tidal capacity of the river, that is to say, the difference in the quantity of the water which is contained by the river at high water and at low water, with the above stated mean range of tide, is 616,634,400 cubic feet above London Bridge, and 13,562,903,900 cubic feet below the same, making a total of 14,179,538,300 cubic feet.

Now, as has been already stated, this body of water is derived from three sources, viz., the sea, the land drainage, the sewage: and it is necessary in the next place to ascertain the relative quantities furnished from each of these sources.

The downward flow of the Thames at Seething Wells, near Kingston, a short distance above Teddington Weir, and beyond the influence of the tides, was gauged daily for eleven years by Mr. Taylor, and the result obtained was an average annual discharge of 500,000 millions of gallons, which, reduced to a mean daily flow, would equal 1,369,800,000 gallons. This is, however, the drainage of only 3676 square miles, whereas the whole area of the Thames Valley is 5162 square miles; and if we assume, as may very fairly be done, that the quantity discharged from the lower portion is in the same proportion, we shall have for the total mean daily discharge from the drainage of the Thames Valley 1,923,626,000 gallons, a quantity which, we may incidentally remark, is about one-third of the rainfall.

From the above, however, must be deducted 100,000,000 gallons, which is daily abstracted from the river above Teddington Weir, for the supply of water to the metropolis, leaving a total quantity of 1,823,626,000 gallons, or 291,780,160 cubic feet for the mean daily discharge, being 145,890,080 cubic feet as the mean quantity of river water contributed each tide.

The mean quantity of the sewage discharged into the Thames from the two outfalls at Barking and Crossness may be taken at 120,000,000 gallons daily, equivalent to 9,600,000 cubic feet every tide, making with the river water a total of 155,490,080 cubic feet, which being deducted from the mean quantity already stated as that which enters the river every tide, we have 14,024,048,220 cubic feet as the mean quantity of sea water which enters the Thames every tide.

It is difficult to form a true idea of the relative values of such large numbers, and, therefore, it is better to reduce them to a percentage, when we obtain the following result namely, that the mean composition of the Thames water is as follows, namely:

Sea water	98.91
River water	1.02
Sewage water	.07
	100.00

That is to say, the actual mean quantity of sewage in the tidal portion of the River Thames, extending from Teddington to Yantlet Creek is only 0.07 per cent., or otherwise expressed, only one 1477th part of its whole bulk.

Futhermore, it must be borne in mind that owing to the circumstance of the river water always being delivered at the upper end of the elongated reservoir, no

less than sixty miles in length, while the ultimate discharge is wholly from the lower extremity, the composition of the water varies greatly, being always much freer from sea water and sewage in the upper portion than the lower. In point of fact, it must be evident that in the case of a stream which has a certain quantity of river water, that is, as we have already defined it, water derived from the rainfall and discharged into the river by surface drainage and land springs, there must always be a point, even in the tidal portion, above which no contamination can exist from sea water or other matters which enter the river near the lower portion of its course.

The foregoing is a statement of the average result, the actual amount of contamination by sewage at any given time and place must depend upon the recent past rainfall and upon the state and condition of the tides, but at no time and under no circumstances can the amount of the sewage contained in the Thames water be raised sufficiently above its average value of one 1477th part to produre any appreciable pollution, far less to afford any ground for the statments to which previous allusion has been made.

Generally, it is obvious that considerable care should be taken in the selection of the points of discharge of sewage matter into tidal rivers, and of the times and conditions of such discharge.

One of the most essential of these conditions being that the sewage shall be so discharged as to be carried into the main stream, in such a manner that it may be commingled with a sufficient bulk of water; and that water traveling with sufficient velocity to insure no deposition by precipitation of any of the contained matter being possible.

Again, the point selected should be one where the course of the stream is direct, and not subject to eddies, or sets upon either of the shores; so as to insure the thorough absorption and mixture of the sewage with the main bulk of the river, and to prevent any deposit taking place upon the foreshores.

Where populous places exist upon the banks of the river, it is, of course, necessary that no sensible pollution of the stream from sewage matter should be suffered in the neighborhood of such place, and in most cases there are two modes of obtaining this result, namely, by the removal of the point of discharge to a sufficient distance below the town, and by the discharge of the sewage during only a limited portion of the ebb tide. To effect the first object, it will be necessary to construct sewers probably of a considerable length, and to effect the second, to form tanks of sufficient capacity to permit the sewage to accumulate during the intervals between the times of discharge.

It is obvious, therefore, that there is an ample field for the skill of the engineer to be exercised, in so designing works for the discharge of sewage into tidal rivers, as to fulfil in a perfect manner the foregoing essential conditions, and that it is under such conditions only that such discharge should be permitted.

THE INFLUENCE OF SILICON ON CAST STEEL.

By M. POURCEL, of Terre Noire.

From "Iron."

THE following note was communicated to the Societé de l'Industrie Minérale, at the September meeting. "The writer begged to recall the attention of members to the subject of cast steels, homogeneous and free from blow-holes, which was discussed at considerable length at one of the Paris meetings, when different opinions were advanced as to the advantages and disadvantages of obtaining these steels, more particularly with reference to quality, either by mechanical or chemical means. In the first place, if the gas is prevented from escaping from the steel, and consequently the blow-hole from forming, we shut up the wolf in the sheep-fold—so M. Grüner affirms (*ou enferme le loup dans la*

bergerie)—which is certainly a disadvantage.

But does this disadvantage really exist? The wolf is the oxygen, or rather the carbonic acid, and when a bath of steel has been previously deoxidised by the addition of sufficient manganese, and the perfect malleability of the metal when hot, has been assured before casting, by means of test samples, it may be taken for granted that it no longer contains oxide of iron, except the merest trace. But nevertheless, at the moment of solidification, the steel gives off carbonic oxide gas; and whether this gas exists in solution, or whether it arises from the intermolecular reaction of the carbide of iron of the steel on the oxide of iron, which is formed during the action of casting, it is not less the cause of the silvery blow-holes so frequently met with in blocks of steel."

The theory of these reactions put forward by the writer, at the November meeting, 1876, was based on most carefully observed facts, and no new fact has come to light up to the present time to contradict it. Whatever mechanical means may be employed to prevent the formation of the blow-hole in the mass of steel at the moment of its solidification, if the metal has been deoxidised before casting, and contains an excess of .2 per cent. to .5 per cent. of manganese, it is certain that the quality will in no way be altered, and that the result will be most satisfactory. In the second place, another opinion advanced by Mr. Vicaire, gives the preference to mechanical action over every chemical reaction, as the former introduces no foreign element into the steel. Mr. Vicaire is of opinion, for instance, that the silicide of manganese added as the chemical reagent to prevent the formation of blow-holes, affects the qualities of the metal, by leaving in it a foreign element, namely, silicon, although in very small proportions, say .2 per cent. to .3 per cent. In this case, let us examine to what extent the metal is affected—if at all. The writer sets aside the possibility of obtaining practically a metal free from silicon, a question of considerable interest, and upon which he touched in speaking of the "influence of the nature of the pots used in the manufacture of cast (crucible) steel, of the chemical composition of the steel," at the July meeting, 1877. It may be mentioned:

(1) That the best brands of English tool steel, made in crucibles from cemented Swedish iron, rarely contain less than .1 per cent. silicon, and generally from .1 per cent. to .3 per cent. (1) That Krupp's cast steel, according to the analyses of M. Boussingault, contains a remarkable quantity of silicon, .3 per cent. to 5 per cent.; and (3) that French cast steels in no wise vary in this respect from similar English steels; and lastly, that the metal which for so long was considered the ideal of steel, was never free from silicon.

We have, therefore, only to examine whether two steels, differing only in their chemical composition by one or two thousandths of silicon, really show any wide difference in their physical and mechanical qualities. All the experiments that have been made in various quarters to determine the action of silicon in steel, have led to the same conclusion, namely, "that it plays the part of carbon, although less energetically," Swedish chemists agree on this point, and Mr. Akerman, whose opinion is highly valued in Sweden, considers that, in order to obtain steel of the mildest description, the silicon as well as the carbon should be eliminated. The writer also holds this view. Only traces of silicon are allowed to remain in plate steel manufactured at Terre Noire. An examination of "Experiments on the Qualities of Plates," published by the "Jernkotoret" of Stockholm, will show that Terre Noire Siemens-Martin steel plate contains: Carbon, 0.20 per cent.; silicon, 0.025 per cent; phosphorus, 0-08 per cent.; manganese, 0.235 per cent.; and sulphur, 0.02.

The action of silicon may be classed with that of the hardening constituents of steel—carbon and manganese; but compared to that of carbon its influence is slight. Professor Mrazek, whose work on this subject has been published in the *Bulletin de l'Industrie Minérale* concludes from his experiments that, as far as manipulation in the hot state is concerned, the effect of silicon is three or four times less than that of carbon; and, similarly, Mr. Mussy states in a communication to the *Bulletin*, that ingots had been manufactured at his works contain-

ing as much as 2 per cent. silicon, but little carbon and manganese, and had undergone, without difficulty, the necessary hammering and rolling for plates and similar articles. The writer must, however, express surprise at Mr. Mussy's statement that the steel in question contained but little manganese: he can hardly understand how a cast metal containing 1 per cent. of silicon only, even with very little carbon, can stand the work of the hammer, unless it contains .6 to .8 per cent. of manganese.

Assuredly a metal containing 2 per cent. of carbon would act very differently. Consequently, under ordinary circumstances, when the percentage of carbon permits of easy manipulation when hot, *i.e.*, when this percentage of carbon remains between .7 per cent. to .9 per cent., or even 1 per cent., the presence of an additional .1 per cent. or .2 per cent. of silicon cannot affect to any extent the malleability of the metal in the hot state.

But is there any necessity for examining the behavior in the hot state of a metal destined for the production of castings which have to undergo no hammering, but simply finishing in the lathe or planing machine? It appears rather that the question should be confined to determining whether the presence of silicon within the specified limits of .2 per cent. or .3 per cent. influences the mechanical properties of the metal, its resistance to shock, tensile strain, crushing strain, etc. Professor Mrazek, who has made experiments to determine the tenacity of the metal cold, admits that $\frac{4}{10}$ths per cent. of silicon do not diminish the tenacity more than $\frac{1}{10}$th per cent. of carbon. Amongst the thousands of tests for tensile strains and resistence to shock made at Terre Noire, on cast steels containing at least .1 per cent. of silicon, and at most .4 per cent., one fact has been established, namely, that two steels containing equal quantities or nearly so of carbon, manganese, and phosphorus, both being equally pure, and differing only by .1 per cent. to .3 per cent. of silicon, give mechanical results differing but slightly. That containing most silicon shows rather less elongation but higher tensile strain, and behaves as if it were slightly more carburized. Without attempting to fix an exact law, it has been observed that the increase of tensile strain given by .1 per cent. of carbon amounts to 6 kilos per square millimetre on the average; whilst the increase due to .1 per cent. silicon scarcely exceeds 1 kilo, and that the difference in resistance to shock is scarcely appreciable with variations of .1 per cent. to .3 per cent. of silicon.

It remains to be examined whether the properties of annealing and tempering are influenced by the presence of silicon. The researches of Colonel Caron, on the behavior of silicon in steels, has proved the property of this body to displace, at a red heat, the carbon from its combination with iron.

Colonel Caron has come to the conclusion that in steels containing silicon—he does not say how much—the carbon, after several heatings, passes into the graphitic form, and that the metal, consequently, loses the property of tempering.

Silicon, as shown by Mrazek, affects the tempering property but very slightly, its influence in this respect, as compared with carbon and manganese, is hardly appreciable. This is a very favorable property, and entirely precludes the fear of the metal being rendered fragile on tempering by the incorporation of a few thousandths of silicon. As regards the effect of silicon in diminishing the tempering properties of the steel after repeated heatings, its influence might, no doubt, be injurious in tool steel.

A tool will lose its hardness more or less rapidly in its work, and one of the chief qualities of tool steel is the faculty which permits of its being tempered and softened almost indefinitely. But this objection almost vanishes when we come to consider the steel required for castings of large dimensions, which require no hammering. It is a matter of slight importance that this metal should have a tendency to lose its tempering power after a certain number of heatings; besides, the proof of this tendency is still wanting.

In fact, it must be borne in mind that the conclusions arrived at by Colonel Caron were deduced from a limited number of tests made on a particular metal, where carbon and silicon were incorporated alone in the presence of each other, in the absence of manganese.

Now, in steel castings of large size, manganese is always present, and its presence modifies the tendency of silicon to diminish the amount of carbon combined with the iron. The writer adduces, as an instance, a pig-iron containing 3 per cent. silicon, 2 per cent. carbon, and .1 per cent. to .2 per cent. manganese, which showed a grey fracture with the carbon in the graphitic state, and a sudden cooling, failed to effect the solution of the carbon. Cast into an iron mold, it took no chill. As soon, however, as the amount of manganese is increased, the effect of the silicon is partly neutralized, and when the proportion of these two bodies is that of the equivalents $\frac{Mn}{Si}$, the grey specks in the fracture disappear and it becomes perfectly white. As a rule, pig-iron containing silicon and manganese in the specified proportions, takes chill "in proportion to the percentage of carbon," as an ordinary pig-iron free from these bodies. If the same observation be applied to the case of steel, it will be readily understood why a metal containing at the same time silicon and manganese, in definite proportion, may show results differing from those obtained by Colonel Caron, and may acquire by tempering all the qualities of superior metal.

As regards the proportion of manganese to be left in the steel, it will vary from .2 per cent. to .5 per cent. for .01 per cent. to .35 per cent. of silicon. This law is equally applicable to phosphorus. A good idea of the changes of grain of solid cast steels, under the influence of tempering, may be obtained from the fractures exhibited in the Terre Noire Pavilion at the Exhibition; the detailed catalogue of each sample gives all the figures of the results obtained from mechanical tests before and after tempering, as well as the chemical composition.

We may, therefore, reasonably conclude that the presence of silicon to the extent of .1 per cent. to .3 per cent. in solid cast steel obtained by chemical reaction, affects neither its physical nor mechanical qualities. Recourse must be had to infinitely small quantities (*faire valoir des infiniments petits*) to determine the difference existing between this steel and steel obtained without the addition of silicide of manganese by any mechanical process whatever.

A DISCUSSION OF THE CONTINUOUS GIRDER WITH EXAMPLES.

By M. S. HUDGINS.

Written for Van Nostrand's Magazine.

In the year 1825 Navier first announced the now well-known principle, that the extension and compression of the fibers of a beam on both sides of the neutral axis, or more correctly, the neutral plane were proportional to their distances from the neutral plane. From this he deduced the equation of the elastic line, and applied it to the continuous girder of special form.

In 1857 Clapeyron made known his celebrated theorem of the three moments; that is, the consideration of the moments over the piers, and the formation of an equation between the moments over any three consecutive piers. He applied it only to uniform loads over a whole girder or span. The theory of continuous girders is considered to be due mainly to Clapeyron. This publication attracted the attention of the mathematicians to the subject, and it has since been greatly improved, but Clapeyron may be considered as having made the foundation for them all.

In 1862 Winkler gave a general theory, and in the same year a like work was given by Bresse. Winkler, in 1867, put forth a general theory with suitable analytical formulæ thus extending his former work. Weyrauch, in 1873 published the fullest and most complete work on the subject, leaving little to be added or desired. The French and Ger-

man mathematicians have done most of the work in this department of applied mathematics, very little having been done by any others.

Before going into our subject we will introduce without demonstration the simple formulae for curvature, slope and deflection, as they will come in farther on in the discussion. Their proof can be found in the ordinary books on applied mechanics. Let r be the radius of curvature of the beam, M the moment of resistance at any cross-section, and I the moment of inertia. Then we will have $\frac{1}{r}=\frac{M}{EI}$, E being the modulus of elasticity. The maximum value of r can be found for any particular load by the substitution for M of its value for such load, and then applying the maximum and minimum test. Let i be the slope of the beam at any point, and i_0 its slope at the origin, then $i=i_0+\int_0^x \frac{dx}{r}$. If there is no slope at the origin $i=\int_0^x \frac{dx}{r}$. (1). The steepest slope under a given load W is $i_1=\frac{M'''Wc^2}{En'bh^3}$ found from (1) by integration and proper substitution. M''' is a factor depending upon the distribution of the load, manner of support, and form of cross-section, $c=l$ or $2l$ as the beam is supported at one or both ends, $n'=\frac{I}{bh^3}$ (1'), b the breadth and h the depth of the circumscribing rectangle. The mode of calculation of m''' will be given in the examples.

The deflection $v=\int_0^x i\,dx$ (2) under a given load W, $v=\frac{n'''Wc^3}{En'bh^3}$ (2') as found from equation (2). n''' depends upon the distribution of the load, mode of support and form of section. It will be calculated in the examples. There is much similarity between these formulae for slope and deflection.

In discontinuous beams the calculation of the shearing force, bending moment, curvature, slope and deflection are direct processes, going step by step from the calculation of one of these quantities to that of another. In continuous beams the process is one of elimination between these quantities. A beam is in the state of a continuous beam when a pair of equal and opposite couples act on it in the vertical, longitudinal, sectional planes at its points of support, of such magnitude as to maintain its longitudinal axis horizontal there. In the figure let CC represent a beam supported at C and C and so fixed as to have its longitudinal axis horizontal at those points instead of having the slope i which it would have were it not fixed or continuous.

At each of the points C and C there is a uniformly-varying horizontal stress, a thrust below and pull above the neutral plane; the moment of this couple is equal and opposite to the moment of the couple maintaining the beam horizontal at C; knowing that moment we can find the stress on the material; then the effect on the curvature, slope, deflection and strength of the beam.

To do this we proceed as follows:—Determine the slope i, which the beam would have at C were it not held horizontal there under the constant moment $M_1 i_1'=\int_0^x \frac{1}{r}\,dx=\int_0^c \frac{M_1}{EI}dx=\frac{M_1 C}{EI}$ and $M_1=\frac{EIi_1}{C}$. This value of M_1 is the moment of the stresses in the beam at the point C. Since it tends to produce convexity upward we call it $-M_1$. The load on the beam will tend to produce convexity downwards. Let M be the moment of flexure at any point of the beam were it simply supported at C and C. The actual moment at any point will now be $M-M_1$. The substitution of this value for M in the formulæ for curvature, slope and deflection will show the change in these quantities produced by making the beam horizontal over the points of support or making it continuous. Where M is greater than M_1 the beam will be convex downwards, where less, convex upwards; where $M=M_1$ the moment of flexure, and consequently the curvature vanishes; these are called points of contrary flexure; at these points thebeam is subject to shearing force only.

(Ex. 1). Let us apply these principles to a beam of uniform section symmetri-

cally loaded. Our formula for the slope gives $i_1 = \frac{m'''Wc^3}{En'bh^3}$, $= \frac{2m''mWc^3}{En'bh^3}$, m''' being $= 2m''m$, where $m = M_0 \div Wl(3)M_0$ being the maximum bending moment in a free beam. We have found $M_1 = \frac{EIi_1}{c} = \frac{n'Ebh^3i_1}{c}$ since $I = n'bh^3$ see eq. (1'), substituting for i_1 its value, $M_1 = 2m''mWc = m''mWl = m'''M_0$ from eq. (3).

We have now to determine m''. The value of i the slope may be written

$$(4) i = \int \frac{MI_0}{IM_0} \cdot \frac{M_0}{EI_0} dx = \frac{M_0}{EI_0} \int \frac{MI_0}{IM_0} dx$$
$$= \frac{mWl}{En'bh^3} \int_0^c \frac{MI_0}{IM_0} dx = \frac{mWl}{En'bh^3} m''c,$$

I_0 being the max. moment of inertia, $\frac{MI_0}{IM_0}$ is a numerical ratio, and m'' is the sum of the various values of this ratio, or $m''c = \int_0^c \frac{MI_0}{IM_0} dx$. In this case $M = \frac{c-x}{2}W$. $M_0 = \frac{cW}{2}$, and the beam being of uniform cross-section $\frac{I_0}{I} = 1$, and $\frac{M}{M_0} = 1 - \frac{x}{c}$ $\therefore m''c = \int_0^c \left\{1 - \frac{x}{c}\right\} dx = \frac{1}{2}c$ $\therefore m'' = \frac{1}{2}$, $m = M_0 \div Wl = \frac{lW}{4} \div lW = \frac{1}{4}$, $m''' = 2mm'' = \frac{1}{4}$. Let M_0' be the actual bending moment at D. Then $M_0' = M_0 - M_1 = M_0 - m''M_0 = (1 - m'')M_0$. The greatest moment of flexure must be either at D or C, or at both if they are equal, but for a uniform section, m'' is never less than $\frac{1}{2}$ $\therefore$ the greatest moment may be at C or at C and D together, but never at D alone.

The deflection is found by subtracting that due to the uniform moment M_1 from that which the beam would have were it simply supported at C and C. We proceed thus: The deflection as found in eq. (2') is

$$v = \frac{n'''Wc^3}{En'bh^3} = \frac{2mn''Wc^3\frac{l}{2}}{En'bh^3},$$

n''' being taken equal $2mn''$ where m has been explained, and n'' will be found farther on. $mWl = M_0$ and $n'bh^3 = I$ $\therefore v = \frac{n''M_0c^2}{EI}$, but $M_0 = \frac{M_1}{m''}$ $\therefore$ $v = \frac{n''}{m''} \frac{M_1c^2}{EI}$ $= \frac{M_1c^2}{EI}$ = the deflection the beam would have were it simply supported at C and C. This must be diminished by the deflections due to the uniform moment M_1. The curvature due to that moment is $\frac{1}{r} = \frac{M_1}{EI}$, $\therefore$ the slope is $i = \int_0^x \frac{dx}{r} = \int_0^x \frac{M_1}{EI} dx = \frac{M_1x}{EI}$, and the deflection $v' = \int_0^c i\, dx$ $= \int_0^c \frac{M_1x}{EI} dx = \frac{M_1c^2}{2EI}$.

Now the true deflection of the beam equals $v - v' = v_1 = \left\{\frac{n''}{m''} - \frac{1}{2}\right\} \frac{M_1c^2}{EI}$ equals, (since $M_1 = m''M_0$), $\left\{n'' - \frac{m''}{2}\right\} \frac{M_0c^2}{EI}$.

From this we see that by fixing the ends or making the beam continuous it is made stiffer in the ratio n'' to $\left\{n'' - \frac{m''}{2}\right\}$, n'' is obtained as follows, $v = fi\, dx$ which from equation (4) can be written $v = \int\int \frac{MI_0}{IM_0} \frac{M_0}{EI_0} dx^2 = \frac{mWl}{En'bh^3}$ $\int\int \frac{MI_0}{M_0l} dx^2 = \frac{mWl}{En'bh^3} n''c^3$ $\therefore n''c^3 = \int\int \frac{MI_0}{M_0l} dx^2$. Now in this case, as has been shown, $\frac{MI_0}{M_0l} = 1 - \frac{x}{c}$, $\therefore$ $n''c^3 = \int_0^c \int_0^x \left\{1 - \frac{x}{c}\right\} dx^2 = \frac{1}{3}c^3$ $\therefore$ $n'' = \frac{1}{3}$ and as $n''' = 2mn''$, but m has been shown equal to $\frac{1}{4}$ in this case $\therefore n''' = 2 \cdot \frac{1}{4} \cdot \frac{1}{3} = \frac{1}{6}$.

The actual moment of flexure is $M - M_1 = M - m''M_0 = M - \frac{1}{2}M_0 = M\frac{c-x}{2} - \frac{1}{4}Wc = \frac{W(c-2x)}{4}$ $\frac{1}{r} = \frac{M}{EI} = \frac{W(c-2x)}{4EI}$ $r = \frac{4EI}{W} \cdot \frac{1}{c-2x}$. The point at which r is a maximum can be found thus; $\frac{dr}{dx} = \frac{8EI}{W} \cdot \frac{1}{(c-2x)^2}$, putting it equal to o we get $x = \frac{1}{2}c$. The point at which r is a maximum and, consequently, the curvature a minimum. The points of contrary flexure are found by solving the equation $M - M_1 = o$ or $W\frac{c-x}{2} - \frac{1}{4}Wc = o$ whence $x = \frac{1}{2}c$, therefore as we should have ex-

pected the points of flexure are points of minimum curvature. The slope $i=\int_o^{x'}\frac{dx}{r}=\int_o^{x'}\frac{W(c-2x)}{4EI}dx=\frac{W}{4EI}(cx'-x'^2)$.

We will now determine the equation of the elastic line and apply it to this particular case. We have for the radius of curvature $\frac{1}{r}=\frac{M}{EI}$, or $EI\frac{1}{r}=M$ (5) but from the formula for the radius of curvature we have $r=\frac{\left\{1+\left(\frac{dy}{dx}\right)^2\right\}^{\frac{3}{2}}}{\frac{d^2y}{dx^2}}$, but the curvature being very small $\left\{\frac{dy}{dx}\right\}^2$ may be neglected in comparison with unity $\therefore r=\frac{1}{\frac{d^2y}{dx^2}}$ or $\frac{1}{r}=\frac{d^2y}{dx^2}$ substituting this value of $\frac{1}{r}$ in equation (5) we get $EI\frac{d^2y}{dx^2}=M$. The equation of the elastic line in cartesian cöordinates. The value of M for this case as has been shown is $\frac{Wc}{4}-\frac{Wx}{2}$. Substituting this in the eq. of the elastic line we have $EI\frac{d^2y}{dx^2}=\frac{Wc}{4}-\frac{Wx}{2}$ or $\frac{d^2y}{dx^2}=\frac{1}{EI}\left\{\frac{Wc}{4}-\frac{Wx}{2}\right\}$ integrating $\frac{dy}{dx}=\frac{1}{EI}\left\{\frac{Wc}{4}x-\frac{Wx^2}{4}\right\}+C_1$ making $x=o$ $C_1=\frac{dy}{dx}$ the tangent of the angle made by the tangent at the origin $\therefore \frac{dy}{dx}=\frac{1}{EI}\left\{\frac{Wc}{4x}-\frac{Wx^2}{4}\right\}+t_1$ integrating again $y=\frac{1}{EI}\left\{\frac{Wc}{8}+^2-\frac{W}{12}+^3\right\}+t_1xt$ a construction which disappears by making $y=o$ when $x=o$.

If now the beam is horizontal at the origin, or perfectly continuous, $t_1=o$ and the eq. of the elastic line is $Y=\frac{1}{EI}\left\{\frac{cx^2}{8}-\frac{x^3}{12}\right\}W$. Let us now find the points of inflection of this curve and see if they agree with the points already found. Placing $\frac{d^2y}{dx^2}=o$ we find $\frac{c}{4}-\frac{x}{2}=o$ or $x=\frac{c}{2}$ $\frac{d^2y}{dx^2}=\infty$ gives $x=\infty$ and does not apply. Now substituting in $\frac{d^2y}{dx^2}$ respectively $\left\{\frac{c}{2}+h\right\}$ and $\left\{\frac{c}{2}-h\right\}$ we find it changes sign $\therefore$ at $x=\frac{c}{2}$ there is a point of inflection as has been shown by the solution of the eq. $M-M_1=o$. Solving the eq. $\frac{dy}{dx}=o$ $x=c$ $\therefore$ the point of max. deflection is at the center as would be expected. After having found the points of inflection A and A, the beam can be treated as though it were composed of three simple beams. First, as a beam CA fastened at C and loaded at A. Second, as a beam ADA supported at both ends A and A. Third, as a beam AC fastened at C and loaded at A. And the slope, curve and deflection may be found by the solution of these cases of simple beams. In the same way if the beam extended on over other piers it could be revolved into simple beams, and discussed as in the corresponding cases of simple beams.

We now come to the fundamental theory of continuous girders known as the theorem of the Three Moments, with the load distributed in any manner whatever.

Let $x=o$, $y=o$ and $x=l$, $y=o$ be the co-ordinates of two adjacent points of support, x being taken horizontal. Let the vertical forces be positive downwards, at any point x between these two points of support let w be the intensity of the loading per unit of span, and EI as before the product of the modulus of elasticity and moment of inertia, all of which may be uniform or variable, continuous or discontinuous.

The following double and quadruple integrals will come in for which we will use the following symbols, viz.,

$$\int\int wdx^2=m,\ \int\int\frac{dx^2}{EI}=n,\ \int\int\frac{xdx^2}{EI}=q$$

$$\int\int\frac{dx^2}{EI}\int\int wdx^2=V.$$

Let the lower limit be $x=o$. When the integration extends over the whole

span, denote it by affixing 1 as n_1, q_1. Let $-F$ be the upward shearing force near the point of support ($x=o$), M_o the bending moment, and T the tangent of the inclination at the point of support. At any point x of the span, let M be the moment.

Now the sum of the moments of all the forces acting on the beam must be o. $\therefore \Sigma(m_s)$=that sum$=o=M_o-F+M-M$.

$$\therefore M=M_o-Fx+m \qquad (6)$$

To find the deflection y, we have from the equation of the elastic line

$$\frac{d^2y}{dx^2}=\frac{1}{EI}M_o-\frac{1}{EI}Fx+\frac{1}{EI}m$$

integrating between o and x, we get—

$$\frac{dy}{dx}=M_o\int_o^x\frac{dx}{EI}-F\int_o^x\frac{xdx}{EI}+\int_o^x\frac{mdx}{EI}+T$$

integrating again—

$$y=M_o\int_o^x\int_o^x\frac{dx^2}{EI}-F\int_o^x\int_o^x\frac{xdx^2}{EI}+\int_o^x\int_o^x\frac{mdx^2}{EI}+Tx$$

or using the symbols above given,

$$y=M_on-Fq+v+Tx \qquad (7)$$

Now let M_1 be the moment at the farther end of the span, then substituting it for M in eq. (6),

$$F=\frac{M_o-M_1+m_1}{l} \qquad (8)$$

And since at the farther end $y_1=o$ (9)

$$T=\frac{Fq_1-m_on_1-v_1}{l}=M_o\left\{\frac{q_1}{l^2}-\frac{n_1}{l}\right\}=\frac{M_1q_1}{l^2}+\frac{m_1q_1}{l^2}-\frac{v_1}{l}.$$

Consider now an adjacent span extending from the origin ($x=o$) to $x=-i$ in the opposite direction to the first.

Let the definite integrals for this span be designated by affixing -1, as m_{-1}, n_{-1}. Let $-T'$ be the slope of this span at the point of support, then will be obtained just as before,

$$-T'=_o\left\{\frac{q-1}{l'^2}-\frac{n_{-1}}{l'}\right\}-\frac{M_{-1}q_{-1}}{l'^2}\frac{m_{-1}q_{-1}}{l'^2}-\frac{V_{-1}}{l'} \qquad (10)$$

Adding equations (9) and (10) and clearing of fractions, also denoting $T-T'$ by t the tangent of the angle made by the neutral layers when the continuity is not perfect, there will result,

$$0=M_o(q_1l'^2+q_{-1}l^2-n_1l'^2)-n_{-1}l'l^2)-M_1q_1l'^2-M_1q_1l'^2$$
$$-M_{-1}q_{-1}l^2+m_1q_1l'^2+m_{-1}q_{-1}l^2-V_1l'^2-V_{-1}l'l^2-tl^2l'^2 \qquad (11)$$

which is the general theorem of the three moments. As it is an eq. expressing the relation between the moments over three adjacent piers, M_o being the moment over the pier at the origin, and M_1 and M_{-1} being the moments over the adjacent piers on the right and left.

A continuous girder of n spans has $(n-1)$ such equations and $(n-1)$ unknown moments, the moments at the endmost piers being zero, hence, we can by elimination, find the value of all these unknown moments. When the number of spans is large the elimination would be tedious in practice. But Clapeyron has introduced a system of multipliers called the Clapeyronian numbers which makes the elimination comparatively easy. They are such numbers that the eqs. when multiplied by them and added, all terms containing the moments disappear except one, which can be found directly, then by the same process the other moments can be found. Having found the moments, the inclination T can be found by eq. (9). The shearing force at the origin by eq. (8). The deflection by eq. (7) and the moment at any point in the span by eq. (6). The points of max moment can be found by solving the eq. $\frac{dm}{dx}=o$ and of max. deflection from the eq. $\frac{dy}{dx}=o$, and in the same way the other points of max. or min. change of any of the functions may be found.

(Ex. 2). The application of these formulæ to a continuous girder of any number of spans of equal lengths, alternate spans being heavily loaded *i. e.*, (bearing a load besides the weight of the bridge) will illustrate their use, $M=\frac{wx^2}{2}$; $n=\frac{x^3}{2EI}$, $q=\frac{x^3}{6EI}$ $V=\frac{wx^4}{24EI}$, EI being taken constant for the whole girder, $V=\frac{mq}{2x}$, for a complete span $x=l$, for heavily

loaded span $w=w_0+w_1$, lightly loaded $w=w_0$, n and q are the same for both heavily and lightly loaded spans. Noticing these points we now proceed to the solution of our eq. (11), and on account of similarity of circumstances over each pier, the moments over them all are equal or $M_0=M_1=M_{-1}$ and so for the others.

Reducing eq. (11), q_1 and q_{-1} cancel being taken between $+l$ and $-l$, and since $m_{11}=2V_1 l$ and $mq_{-1}\,q_{-1}=2V_{-1}\,l$. The result is $0=-2M_0n_1+V_1+V_{-1}-tl$,

or $$M_0=\frac{V_1+V_{-1}-tl}{2n_1}=\frac{\frac{(w_0+w_1)l^3}{24EI}+\frac{w_0l^3}{24EI}-tl}{\frac{l^2}{EI}}=\frac{(2w_0+w_1)l^2}{24}-\frac{t}{l}EI$$

If now we suppose the girder *perfectly* continuous $t=o$ and $M_0=\frac{2w_0+w_1}{24}l^2$ (12). For simplicity t will be regarded as zero or the beam perfectly continuous in the remainder of the calculations.

The shearing force $F=\frac{M_0-M_1+m_1}{l}=\frac{m_1}{l}=\frac{w_0}{2}l$ or $(w_0+w_1)\frac{l}{2}$ for light and heavy loads. The slope $T=\frac{Fq_1-M_1n_1-V_1}{l}=\left\{\frac{w_0+w_1}{12EI}l^3-\frac{2w_0+w_1}{48EI}l^3-\frac{w_1+w_1}{24EI}l^3\right\}\div l=\frac{w_1l^2}{48EI}$, $-T^1=\left\{\frac{w_0l^3}{12EI}-\frac{2w_0+w_1}{48EI}l^2-\frac{w_0l^3}{24EI}\right\}\div l=-\frac{w_1l^2}{48EI}$ agreeing with the supposition $T+(-T^1)=t=\frac{w_1l^2}{48EI}+\left\{-\frac{w_1l^2}{48EI}\right\}=o$. Moment at any point in heavily loaded span $=M=M_0-Fx+m=\frac{2w_0+w_1}{24}l^2-\frac{w_0+w_1}{2}lx+\frac{w_0+w_1}{2}x^2$, $\frac{dM}{dx}=-\frac{w_0+w_1}{2}l+(w_0+w_1)x=ox=\frac{l}{2}$. The maximum moment is at the center; substituting this value of x in the equation of the moment, the max. moment $M=\frac{2w_0+w_1}{24}l^2-\frac{w_0+w_1}{4}l^2+\frac{w_0+w_1}{8}l^2=-\left\{\frac{w_0+2w_1}{24}\right\}l^2$.

For lightly loaded span $M=\frac{2w_0+w_1}{24}l^2-\frac{w_0lx}{2}+\frac{w_0x^2}{2}$, max. moment at the center $=\left\{\frac{w_1-w_0}{24}\right\}l^2$. The deflection $y=M_0n-Fq+V+Tx=\frac{2w_0+w_1}{48EI}l^2x^2-\frac{w_0+w_1}{2}l.\frac{x^3}{6EI}+\frac{w_0+w_1}{24EI}x^4+\frac{w_1l^2}{48EI}x$, $\frac{dy}{dx}=\frac{2w_0+w_1}{24EI}l^2x-\frac{w_0+w_1}{4EI}lx^2+\frac{w_0+w_1}{6EI}x^3+\frac{w_1l^2}{48EI}=o$, $x=\frac{l}{2}$ satisfies the eq. and we know from other conditions that the max. deflection is at the center, hence we need not discuss the cubic eq. but substituting $x=\frac{l}{2}$ in the value of y there is obtained the max. deflection for heavily loaded span. To find the same for lightly loaded span we have only to replace w_0+w_1 by w_0.

In this case we will apply the principle used in the first example for finding the moment over the piers to see if the two results agree. The actual moment $=M_1-M_1$, M being the moment were the beam free, and M_1 the constant moment over the piers. Take the origin at the center of the span, $c=\frac{l}{2}$. Let x be the abscissa of a heavily loaded span, and x' of a lightly loaded one.

$M=\frac{w_0+w_1}{2}(c^2-x^2)$ for heavy load, and $\frac{w_0}{2}(c^2-x'^2)$ for light load. ∴ The actual moment for heavy load $=M'=\frac{w_0+w_1}{2}(c^2-x^2)-M_1$, and for light $\frac{w_0}{2}(c^2-x'^2)-M_1$ slope $i=\int\frac{M'}{EI}dx=\frac{1}{EI}\left\{\frac{w_0+w_1}{2}(c^2x-\frac{x^3}{3})\,M_1x'\right\}$ (heavy) and $\frac{1}{EI}\left\{\frac{w_0}{2}(c^2x'-\frac{x^3}{3})-M_1x'\right\}$ for light load.

The beam being continuous i_1 for $x=c$ and $x=-c$, should be the same, equating the two values, we have

$$\frac{w_0+w_1}{2}(c^3-\frac{c^3}{3})-M_1c=-\frac{w_0}{2}c^3+\frac{w_0}{2}\frac{c^3}{3}+M_1c$$

or $\frac{2w_0+w_1}{3}c^3=2M_1c$, $M_1=\frac{2w_0+w_1}{6}c^2$

$=\frac{2w_0+w_1}{24}l^2$

which agrees with the value of M_1 obtained from the general formula. Points of inflection can be found by solving $\frac{d^2y}{dx^2}=o$ or ∞, or by means of the equation $M-M=o$, in either case there will result a quadratic equation giving two points in each span.

(Ex. 3)

A_0	A_1	A_2	A_{n-2}	A_{n-1}	A_n
	a_1	a_2	a_{n-1}	a_n	
Q_0	Q_1	Q_2	Q_{n-2}	Q_{n-1}	Q_n

Let A_0A_n be a continuous girder, A_0A_1 etc., points of support or subject to the action of isolated loads, Q_0Q_1 etc., positive upward action of piers or negative downward action of loads. Consider a section normal to the elastic curve in the span $A_{n-1}A_{n-1}$ a_1 a_2 . . . the lengths of the divisions β_0 β_1 . . . the angles made by the girder at the piers with the horizontal line, w the intensity of the loading. Then the eq. of the elastic line $EI\frac{d^2y}{dx^2}=M$ becomes $EI\frac{d^2y}{dx^2}=\frac{1}{2}(a_1+a_2+\ldots+a_{n-1}+x)^2w-(a_1+a_2+\ldots+a_{n-1}+x)Q_0-(a_2+a_3\ldots+a_{n-1}+x)Q_1-\ldots\ldots-(a_{n-1}+x)Q_{n-2}-xQ_{n-1}$, x being the distance of the section from A_{n-1}; reducing these results,

$$EI\frac{d^2y}{dx^2}=\tfrac{1}{2}(a_1+a_2+\ldots+a_{n-1})^2w+(a_1+a_2+\ldots+a_{n-1})wx+\tfrac{1}{2}wx^2-a_1Q_0-a_2(Q_0+Q_1)-a_3(Q_0+Q_1+Q_2)-\ldots\ldots-a_{n-1}(Q_0+Q_1+\ldots+Q_{n-2})-x(Q_0+Q_1+\ldots Q_{n-1}).$$

Integrating $EI\left\{\frac{dy}{dx}-\tan.\beta_{n-1}\right\}=\frac{1}{2}(a_1+a_2\ldots+a_{n-1})^2wx+\frac{1}{2}(a_1+a+_2+\ldots+a_{n-1})wx^2+\frac{1}{6}wx^3-[a_1Q_0+a_2(Q_0+Q_1)+a_3(Q_0+Q_1+Q_2)+\ldots\ldots+a_{n-1}(Q_0+Q_1+Q_2+\ldots\ldots+Q_{n-2})]x-\frac{1}{2}(Q_0+Q_1\ldots\ldots+Q_{n-1})x^2.$

Integrating again and noting that when $x=o$, $y=y_{n-1}$, there results

$EI(y-y_{n-1}-\tan.\beta_{n-1}x)=\frac{1}{4}(a_1+a_2+\ldots+a_{n-1})^2wx^2+\frac{1}{6}(a_1+a_2+\ldots+a_{n-1})wx^3+\frac{1}{24}wx^4-\frac{1}{2}[a_1Q_0+a_2(Q_0+Q_1)+a_3(Q_0+Q_1)+Q_2)+\ldots\ldots+a_{n-1}(Q_0+Q_1+Q_2+\ldots\ldots+Q_{n-2})]x^2-\frac{1}{6}(Q_0+Q_1x\ldots\ldots xQ_{n-1})x^3.$

The integral equation of the elastic line between A_{n-1} and A_n in the last two equations, making $x=a_n$, $y=y_n$, and $\frac{dy}{dx}=\tan.\beta_n$, they become

$EI(\tan.\beta_n-\tan.\beta_{n-1})=\frac{1}{2}(a_1+a_2+\ldots\ldots+a_{n-1})^2wa_n+\frac{1}{2}(a_1+a_2+\ldots\ldots+a_{n-1})wa^2_n+\frac{1}{6}wa^3_n-[a_1Q_0+a_2(Q_0+Q_1)+a_3(Q_0+Q_1+Q_2)+\ldots\ldots+a_{n-1}(Q_0+Q_1+Q_2+\ldots\ldots+Q_{n-2})]a_n-\frac{1}{2}(Q_0+Q_1+\ldots\ldots+Q_{n-1})a^2_n$. The last one becomes $EI\left\{\frac{y_n-y_{n-1}}{a_n}-\tan.\beta_{n-1}\right\}=\frac{1}{4}(a_1+a_2+\ldots\ldots+a_{n-1})^2wa_n+\frac{1}{6}(a_1+a_2+\ldots\ldots+a_{n-1})wa^2_n+\frac{1}{24}wa^3_n-\frac{1}{2}[a_1Q_0+a_2(Q_0+Q_1)+a_3(Q_0+Q_1+Q_2)+\ldots\ldots+a_{n-1}(Q_0+Q_1+Q_2+\ldots\ldots+Q_{n-2})]a_n-\frac{1}{6}(Q_0+Q_1+Q_2+\ldots\ldots+Q_{n-1})a^2_n$.

These equations taken in conjunction with the two general equations of equilibrium given below are sufficient to solve the problem, $(a_1+a_2+a_3+\ldots\ldots)w=Q_0+Q_1+Q_2+\ldots$ and $a_1Q_0+a_2(Q_0+Q_1)+a_3(Q_0+Q_1+Q_2)+\ldots\ldots=\frac{1}{2}(a_1+a_2+a_3+\ldots\ldots)^2w$, being the general equations. The eqs. deduced are true for all indices $n=1$, 2, 3, &c. This method of treatment is the one given by Scheffler; it first becomes applicable when the number of spans exceeds three. The number of equations for any example may be reduced one half when the conditions on each side of the center of the girder are identical. If the points of support and isolated loaded points are in the same horizontal line y_n, y_{n-1}, &c., disappear.

The method of using and determining the Clapeyronian numbers will now be given. These numbers play an important part in the solution of continuous girders. Let the number of moments be $(n+1)$, the moments at the two abutments M and M_{n+1} equal zero. The equations involve these moments and constants, depending upon the length of the spans, intensity and distribution of the loading, they will be of the type

$$\left.\begin{aligned} &a_1M_2+b_1M_3=A_1\\ &a_2M_2+b_2M_3+d_2M_4=A_2\\ &a_3M_3+b_3M_4+d_3M_5=A_3\\ &\ldots\ldots\ldots\ldots=\ldots\\ &a_{n-1}M_{n-1}+b_{n-1}M_n=A_{n-1}. \end{aligned}\right\}$$

Multiplying the first by c_2, the second by c_3 and so on, we will get,

$a_1c_2M_2 + b_1c_2M_3 = c_2A_1$

$a_2c_3M_2 + b_2c_3M_3 + d_2c_3M_4 = c_3A_2$

$a_3c_4M_3 + b_3c_4M_4 + d_3c_4M_5 = c_4A_3$

. . . . . = . . .

$a_{n-1}\,c_n\,M_{n-1} + b_{n-1}\,c_n\,M_n = c_n\,A_{n-1}$

Adding these equations we get

$(a_1c_2 + a_2c_3)M_2 + (b_1c_2 + b_2c_3 + a_3c_4)\,M_3 + (d_2c_3 + b_3c_4 + \ldots)M_4 + \ldots\ldots + (\ldots + b_{n-1}\,c_n)M_n = A_1c_2 + A_2c_3 + \ldots\ldots + c_n\,A_{n-1}$

This equation involves all the moments with only known and arbitrary constants. These are arbitrary constants; c_2, c_3, c_4 &c., which are the Clapeyronian numbers, may be so chosen as to make the coefficients of all the moments disappear except one, which will then be known. In the same way the other moments may be obtained. By placing the coefficients of the moments we wish to disappear equal to zero, the relation between the Clapeyronian numbers is easily seen.

ON A NEW DYNAMOMETER FOR LOCOMOTIVES.

By H. KILLICHES.

From "Die Eisenbahn," Abstracts published by the Institution of Civil Engineers.

This dynamometer is intended to answer the same purpose for locomotives as the friction brake dynamometer for ordinary engines. The instrument is fixed between the engine and the first carriage and records, by means of a pointer moving over a face like that of a gas meter, the number of hectometer-tonnes performed by the engine in any given time. For this purpose the revolutions of one pair of wheels are measured by means of a worm fixed on the axle, engaging with a small worm wheel which is mounted on a long spindle reaching from the axle to the recording apparatus between the engine and the carriage. Here the motion is transferred, by means of a pair of bevel wheels, to another small shaft, which carries a large disk. Against the face of this disk presses a small wheel, connected with a spiral spring, which through a system of levers, is extended by and in proportion to the strain on the draw-bar. When this strain is zero, the wheels rest exactly on the center of the disk; but when the strain has any other value, the wheel is pushed outward towards the circumference of the disk through a proportionate distance and it then revolves by friction with the same velocity as the portion of the disk at that particular distance from the center. Thus, it will be seen that when the speed of the axle is constant, the revolutions of the small wheel are proportional to the pull on the draw-bar, and when the pull is constant; the revolutions of the small wheel are proportional to the speed of the axle or to the distance run by the train; therefore, when both vary, the revolutions of the small wheel are proportional to the product of these two (the pull on the drawbar and the distance run by the train), *i. e.*, in other words, to the work done by the engine. All that remains is to connect this wheel to the pointer by a train of clock-work, and the latter will then record the work done. Various devices and precautions are described for rendering the principle efficient, and an account is given of experiments made with the apparatus on the Archduke Albert railway, in Austria. It was found, for instance, that the greatest variations in the resistance to traction took place in April and May, on account of the changeable weather; and, again, that the traction was less towards evening, because the weather is then generally finer, and there is less wind. The apparatus applied, either to ascertain the average work done during a long trip, or the total work at some special part of the line. In the latter case, the record must be noted at short intervals, and the speed observed independently. The following important points, among others, may be determined by the use of this dynamometer :

1. The actual power of an engine, and the proportional consumption of fuel may now, for the first time, be accurately ascertained.

2. The tables of maximum load on inclines, &c., may be corrected and verified. The maximum loads should be varied according to the season of the year, by an amount which will be fixed by the use of the dynamometer.

3. In cases where trains are delayed, &c., the dynamometer will show whether this was due to an increase in the tractive force or to the fault of those in charge of the train.

4. It enables the amount of fuel consumed, in proportion to the work done, to be accurately known, and the prizes for economy given to the drivers to be placed on a rational basis. It must, of course be remembered that it does not give the work done in moving the engine itself, but this can be easily ascertained by other means, and is not subject to much variation from differences of wind and weather.

THE USE OF ZINC IN STEAM BOILERS.

From "Engineering."

THE employment of zinc in steam boilers, like that of soda, has been adopted for two distinct objects, (1) to prevent corrosion, and (2) to prevent and remove incrustation. To attain the first object it has been used chiefly in marine boilers, and for the second chiefly in boilers fed with fresh water. We purpose dealing with each head separately in the above order, and in as popular a manner as the subject will allow.

The suggestion to use zinc for the protection of the copper sheathing of vessels by Sir H. Davy, and his development of this principle in 1824, appears to have suggested to Professor E. Davy, about ten years later, the application of zinc for the protection of the iron buoys in Kingstown Harbor. This is probably the first application of the principle to protect iron against the corrosive agency in sea-water. The application of the same principle to protect the interior of steam boilers against corrosion does not appear to have been attempted before the year 1850. It was not, however, till the introduction of surface condensation for marine engines that zinc can be said to have been extensively used to prevent the corrosion of the iron plates and tubes, which were no longer protected to the same extent by the scale that formed upon them when jet condensers were used.

Zinc has been applied in various ways in marine boilers, viz., by suspending it in plates of various size and number from the stays, and more rarely amongst the tubes where practicable. The zinc plates or bars have been placed in boxes in various parts of the boiler, sometimes for the feed to pass through, and in other cases the zinc has been arranged for the feed to deliver upon it as it enters the boiler. As may be imagined, these various ways of applying the zinc led to very different results. In a great many cases its use was not attended with any apparent advantage, and it was consequently discontinued. In other cases, however, where its application had been made in a more judicious manner, it was more successful, and its use has been continued with very favorable results up to the present time.

It is evident, from the manner in which zinc has been employed in the great majority of cases to prevent corrosion, that the principle of its action has been assumed to be simply chemical; that it had a greater affinity than the iron for the oxygen and acids in the water. In order that this supposed simple chemical action should take place efficiently, and that the corrosive agents throughout the whole body of water should be neutralized, it would be necessary that they should all be brought in contact with the zinc before they could come in contact with the plates and tubes. Were the zinc soluble in water, this condition might be carried out, but as zinc is not soluble, and cannot reach all the corrosive ingredients in solution, or held in

suspension and diffused throughout the water, it follows that all the particles of water must be brought and kept in contact with the zinc for a time in order that it may be really efficacious. That this is likely to take place in a large boiler with a few pieces of zinc cannot be maintained. Were the simple chemical action alone relied upon for the protective action of the zinc, the plates and tubes should be nearly covered with it in order that this action should be effective, since the iron would share with the zinc the corrosive action of the water, in proportion to the surface of each metal exposed. We must then look for some other explanation of the success which has attended the introduction of a few bars of zinc into a large boiler.

The remarkable protection that zinc has afforded in many authenticated cases, can only be explained by ascribing it to galvanic action. When a metal like iron, which is acted upon more or less by a liquid, is brought into contact with another metal like zinc, which has a much stronger affinity for the oxygen of the liquid, or for the acids of the salts contained in solution, the zinc or positive electrode is dissolved and imparts a negative tendency to the iron, which preserves it by preventing the oxygen or acids from acting upon it. In most cases where zinc is employed with advantage to prevent corrosion in boilers, the water is a weak solution of salts. This solution is decomposed by the galvanic current in such a manner that the oxygen and acids are liberated at the positive pole (+zinc), and the hydrogen of the water and metal of the salt at the negative pole (—iron). The decomposition of the water, or electrolysis as it is called, takes place in such a manner that the oxygen of one molecule of water in contact with the zinc is separated, and the liberated hydrogen combines with the oxygen of a neighboring molecule, whose oxygen in its turn combines with the hydrogen of the next molecule, and so the action goes on till the hydrogen of the water in contact with the iron at a considerable distance is liberated, without the hydrogen and oxygen having to cross the water as free gases. It is in consequence of this action that a piece of zinc placed in the middle of a plate of iron has the valuable property of exercising a protective influence over a large surface of which it is the center. The extent of the range of its action will depend upon the purity of the zinc, the nature of the salts in solution, the temperature of the water, and the condition of the surfaces of the zinc and iron. In order that the protective action may take place effectively, it is necessary that the zinc and iron should be in perfect metallic contact. It is extremely probable that the fulfillment or not of this last condition has determined the efficacy or non-efficacy of the application of zinc in the numerous cases where it has been tried with such different degrees of success. Zinc "bottoms" should not be used, nor indeed is some of the spelter in the market sufficiently pure to act to the best advantage. But, as a rule, good commercial English or Belgian zinc may be considered as being sufficient for the purpose. A high temperature is favorable for the setting up of the galvanic current, and therefore for the protection afforded by the zinc.

Besides having the zinc and iron in perfect metallic contact, it is necessary for the maintenance of the galvanic current, upon which the success of the application of the zinc depends, that the surface of the zinc exposed to the water should be kept clean and free from any non-conducting coating that may be formed by the chemical action that ensues on the liberation of the oxygen and acids at the surface of the zinc. This brings us to a very important consideration that is liable to be overlooked.

When the oxygen and acids are set free at the surface of the zinc, oxide of zinc is formed, and this combines with the acids to form salts. These salts are either soluble or insoluble in the water. If soluble they become diffused through the water, the zinc is kept clean, and the galvanic action is sustained at the expense of the zinc. If insoluble the salts tend to collect upon the zinc, which in time becomes coated with them. As this coating is a non-conductor, the galvanic action is gradually arrested, and, in time, ceases altogether, the presence of the zinc being consequently no longer efficacious.

With sea-water the sulphuric and hydrochloric acids liberated from the contained sulphates and chlorides, com-

bine with the oxide of zinc, and from sulphate and chloride of zinc, which are very soluble, hence the successful application of zinc in marine boilers. But in boilers fed with fresh water where the acids liberated are too small in quantity to combine with all the oxide of zinc to form soluble salts, the film of oxide that forms on the surface of the zinc, in time, puts an end to its useful effect.

It is well known that the galvanic current has no effect on the oxygen in solution in the water, and that it is only the oxygen chemically combined with the hydrogen in the water, and in the bases of the salts, that are liberated at the surface of the zinc. The question then arises, how can the zinc protect the iron from the oxygen in solution in the water which may be in contact with the plates? The answer is, by a secondary and chemical process, viz., the hydrogen liberated at the surface of the iron combines with the oxygen in solution and forms water, or the metals liberated from the salts at the surface of the iron unite with this free oxygen and form bases. In fact these metals have such an affinity for oxygen that they attract it from the water and residuary hydrogen is evolved.

We have been led to this length in explaining the principles upon which the success or non-success of zinc depends, as it is likely to be largely employed since the Admiralty Boiler Committee have spoken so strongly in favor of the use of zinc for preventing corrosion. The portions of the Boiler Committee's report treating of the use of zinc, are very valuable, and we shall deal with them in a future article, when we shall also have something to say on the use of zinc for preventing incrustation.

REPORTS OF ENGINEERING SOCIETIES.

AMERICAN SOCIETY OF CIVIL ENGINEERS.—At the recent annual meeting the following persons were elected officers of the American Society of Civil Engineers for the year beginning November 6th, 1878: *President*—W. Milnor Roberts; *Vice-Presidents*—Albert Fink, James B. Francis; *Secretary*—John Bogart; *Treasurer*—J. J. R. Croes; *Directors*—George S. Greene, William H. Paine, C. Vandervoort Smith, T. C. Clarke, Theo. G. Ellis.

ENGINEERS' CLUB OF PHILADELPHIA.—At the last meeting of the Club, Professor Lewis M. Haupt, President, read a paper on "The Scales of Maps and Drawings," giving some simple rules for the removing of ambiguities at present existing. It is evidently incorrect to indicate the scale of a map as so many inches to the mile, or of a drawing, as so many feet to the inch, when the intention is a certain number of miles or feet to the inch of paper. The paper also referred to the great number of scales in use, and the great inconvenience caused thereby, urged the necessity for some measures which should reduce or overcome this defect, and closed by presenting two tables of map equivalents, showing the number of miles, kilometers, chains, poles, meters, yards and feet which are equal to one inch of map, for any scale, and reciprocally the number of square inches of map required to represent one or more units of the above denominations.

Mr. I. W. Morris read a letter from Mr. C. F. Conrad, which gave the following interesting information in regard to the "Butler Mine Fire Cut-off:"

"Before locating the line of the cut-off, I learned of the first fire which they had in the same vein (14 feet thick) in 1856-57, and after careful inquiry learned its position and made my location for the through cut to pass as near as possible through the center of the "old fire." This was done, hoping to find all combustible matter, coal, "gob" and carbonaceous slate burnt to ashes, in which case it would have saved many thousand yards of excavation, as it would have presented an impassable barrier to the progress of the present fire.

This cut-off afforded an opportunity rarely, if ever, equalled to learn truly and fully the work of a fire in a coal mine. It was found the slate above and surrounding the coal and all the "gobb" was burned either to ashes or into slag, resembling ordinary furnace slag, while the pillars of solid coal were perfectly sound and bright. About the middle of the 14-feet vein of coal is an 8-inch line of slate, and this was found burned to a white ash, while the coal above and below were perfectly bright. When the fire reached the end of the workings it made no further progress, but, after burning the fallen rock to ashes or slag, it entered the face of the coal two or three inches and then went out.

Mr. Conrad concludes by saying that he is led to believe that solid coal cannot be burnt in place; that slate rock found in coal veins contains more gas than the coal; that fires in coal mines are fed and live on the "gob" (refuse slate, &c.), and gases, and that "gob" is an excellent reservoir for gas. Ventilation will carry off free gas, but "gob" holds gas as a sponge does water.

Mr. Edward R. Andrews, of Boston, proprietor of the Hayford Creosote Wood Preserving Works, gave a full description of the apparatus employed in his process and of the results obtained by the use of creosoted wood. Decay in wood is due primarily to the fermentation of the albumen of the sap, which commences as soon as the necessary conditions, heat and moisture, are supplied. The aim of all wood preservatives has been to overcome this fermentation by coagulating the albumen. Experiments to produce this result were made as early as 1700.

Bethel, 1837, introduced dead oils as wood preservatives, and to show the success which has attended this process, it is only necessary to state that it is used by every railway in England, where nearly all timbers used in construction are impregnated with creosote. The Hayford process differs from that of Bethel in this particular; the latter can only be applied to seasoned timber, while in the former process timber can be taken as it comes from the saw mill and creosoted in a few hours.

The cost of creosoting railroad ties is from 25 to 30 cents per tie. Paving blocks have recently been treated for the Broadway Bridge, Boston at a cost of $12 per thousand feet, cord measure.

A section of a railroad tie was shown which had been in use in Scotland for over twenty years, and seemed to be in perfect condition; the rail has not cut it, and there are no signs of rot in the spike holes. There is every reason for believing that creosoted ties will last here for twenty years as well as in Europe Already several railroads are using them. In 1875 the Central Railroad of New Jersey laid ten thousand creosoted ties near Bound Brook, which, thus far, show no signs of decay.

In addition to protecting from decay, creosoting is equally a specific against destruction of wood by marine worms. Experiments are being tried on ship timber in the U. S. steamer Vandalia, now in the Mediterranean. This vessel was built at the navy yard in Charleston during 1872. All the timber except the live oak ribs, both inside and out, were creosoted by the Hayford process. The vessel went to sea in 1874, and is expected home next year, when the result of the experiment will be known.

When we take into consideration the enormous drain which is being made on our supply of timber, stripping the forests altogether from many parts of our country, it would seem that we ought to be alive to the importance of preserving timber.

Mr. Percival Roberts, Jr., read a very able paper on the "Strength of wrought iron in structures." He called attention to the great need for more accurate knowledge in regard to the strength of wrought iron, and criticised, in a terse and interesting manner, some of the testing machines and specifications of the present day.

IRON AND STEEL NOTES.

In speaking of the Birmingham wire gauge, the warden of the Standards in his last report says that there is no standard wire gauge, or common agreement amongst those interested as to what are the dimensions in parts of an inch of the several slots or sizes of the true B.W.G. Its sizes are not geometrically or arithmetically progressive, and consequently bear no definite relation to each other. Its origin is obscure, and it would appear that the several slots or sizes arose from time to time as a new wire or a new plate was introduced, and as the exigencies of a particular trade demanded. In Germany, gauges for wire or sheet iron have not yet been officially controlled. The Birmingham gauge, commonly called the "English gauge," is mostly in use in Northern Germany for measuring sheet iron, wire, and hoop iron. In Southern Germany, the B.W.G. is also used, and for the measurement of wires the French gauge, which is a progressive scale of tenths of a millimeter (1 millimeter= 0.0393709 inch) is also used. For sheet iron the "Dillingen gauge," which is a scale of Paris lines (1 line=0.08881377 inch) is also used in Southern Germany. The wire factories in Westphalia use a particular gauge called the "Bergish, or Westphalian." For some time past the question of establishing a uniform wire gauge and a uniform numbering of wires has been energetically agitated in Germany. The manufacturers in Russia use different gauges of English, German and French patterns. In Canada only one gauge is known to mechanics—the Birmingham wire gauge—made by Stubbs, of Warrington. In France measurements are made by the scale of one-tenth of a millimeter as well as by the Birmingham and Dillingen arbitrary guages. In America the B.W.G. is extensively used, but a special committee recently recommended the expression sizes in thousandths of an inch, or in fractions of a millimeter. An international standard gauge is much wanted. Meanwhile, it should be remembered that in any contract, bargain, sale, or dealing, the sizes of wire and metal plates are legally expressed only in Imperial measures or in parts of an inch.

Different Qualities of Iron and Steel.—By C. Grauhan.—The Author describes at full length the characteristics of the different species of steel and iron. Of steels he mentions puddled, Bessemer, Martin, and cast steel, pointing out that generally the first has the coarsest and the last the finest grain; puddled steel generally shows some traces of having been formed of several pieces, while Bessemer and the other qualities, being cast in blocks, are homogeneous. But Bessemer metal is frequently porous, and when worked up for railway axles or similar purposes, the bubbles are first closed by forging, but show themselves again in the form of longitudinal cracks when taken out of the lathe. These bubbles occur seldom in Martin steel, never in cast steel. And a further difference between Martin and Bessemer steel is, that the former contains less silica.

According to the Author, the quality of steel cannot be fairly tested unless it is first hardened, as otherwise a bar which was rolled rather hotter than another would show quite a different texture, although of the same metal. The steel should be heated, forged to bars of a uniform size. and then hardened in water, which process eliminates any chance differences. If a bar thus prepared be broken, the texture, color, and general appearance of the fracture will give a very close approximation to the quality. Of course, although fine-grained steel is better than coarse grained, the former cannot be used for every purpose. Rails and axles, for instance, require coarse-grained, porous, and soft metal. If after sudden im-

mersion in water the grain is as coarse as before, the steel is not fit for hardening and approximates to wrought iron. The finer the grain the harder is the metal and the more carbon does it contain. If the fracture shows a coarse grain and a whitish reflection there is a good deal of phosphorus and silica in the steel, which is, of course, injurious. If it shines blue instead of white the metal is burnt and contains too little carbon.

As a rule, the hardness of steel depends on the amount of carbon it contains, and the quantity of carbon resulting from analysis is used as a measure of its hardness.

Herr Grauhan mentions the different methods of testing iron, of which he prefers the chemical mode, and gives the following results of the analyses of various sorts of iron :

1. WESTPHALIAN BESSEMER IRON.

	Per cent.
Iron	86.912
Carbon	3.200
Silicium	3.140
Manganese	6.180
Phosphorus	0.120
Sulphur	0.070
Copper	0.380

2. WELSH IRON (WHITE).

Iron	94.400
Carbon	2.400
Silicium	0.800
Sulphur	0.700
Phosphorus	1.500
Manganese	0.200

3. SPIEGEL IRON FROM MUSEN.

Iron	82.860
Carbon	4.323
Silicium	0.997
Manganese	10.707
Phosphorus	0.059
Sulphur	0.014
Copper	0.066

4. BESSEMER RAIL FROM A WESTPHALIAN WORKS, WHICH BROKE IN UNLOADING.

Carbon	0.370
Manganese	0.650
Silicium	0.223
Sulphur	0.040
Phosphorus	0.084

5. [CAST-STEEL AXLE FROM A WESTPHALIAN WORKS.

Carbon	0.221
Silicium	0.061
Phosphorus	0.052
Sulphur	0.072
Manganese	0.276
Copper	0.072

6. RETORT-STEEL TIRE OF A WESTPHALIAN WORKS.

Carbon	0.5800
Sulphur	0.0380
Silicium	0.1010
Phosphorus	0.0407
Manganese	0.6080

N.B.—The tenacity of this tire was 71 to 74 kilogrammes per millimeter, or about 43 tons to the square inch.—*Abstracts of Institution of Civil Engineers.*

CHROMIUM augments the hardness and tensile resistance of iron alloys; but it has no "steelifying" properties, and cannot take the place of carbon. Boussingault fused chromic oxide with cast iron in such proportions as to burn all the carbon of the latter with the oxygen of the former; but the non-carboniferous alloy of iron and chromium thus obtained would not temper. Berthier is the real discoverer of the acier chrome, or chromised steel. As long ago as 1821, he indicated the means of introducing chromium into cast steel, and announced that the compound thus formed possessed properties which might render it precious for many purposes. It is now manufactured, says M. Rolland in his "Note sur l'Acier Chrome," just published in Paris; at Brooklyn, N.Y.; Sheffield, England; and in France at Unieux, in the department of the Loire. A sample of ferro-chrome from Brooklyn, analysed by Boussingault, showed 4.29 per cent. of combined carbon and 48.70 of chromium. The ferro-chrome of Unieux contains about 5.4 per cent. of combined carbon and up to 67.2 per cent. of chromium. Chrome steel is made at Unieux, as at Brooklyn, by fusing in crucibles, in a Siemens furnace, fragments of wrought iron or steel of the first quality, with an addition of ferro-chrome calculated for the degree of acieration and hardness required. The steels of Unieux vary in their contents of chromium from 0.5 to 0.9 per cent. Boussingault found in a hard steel from Brooklyn 1.1 per cent. of combined carbon and 0.44 of chromium. Concerning the properties of chrome steel, and the peculiar manipulation required in working and tempering it, M. Rolland gives substantially the same statements as the circulars of the Chrome Steel Company, of Brooklyn. The directions may be summed up in two : For working—except punching, which may be done, it is said, at a moderate temperature—the heat should be high—nearly white at first; for tempering and hardening, a low cherry heat is the best. M. Rolland says, in conclusion, that chrome steel is as yet but little known, and much restricted in its applications.

RAILWAY NOTES.

MR. A. C. FRANKLIN, of Brighton, is bringing out a tram-car motor in which a central wheel is used for propulsion on the common road, no reliance being placed upon the adhesion of the wheels upon the rails. Compressed air is to be employed in long cylinders, in which pistons reciprocate and work racks geared upon pinions upon the driving wheel axle, arrangements being made for producing revolution in one or both directions, whichever way the pistons are moving. Some practical trials will probably be made.

THE employment of wheels larger than those commonly used on American stock has lately occupied much attention. A trial having been made of the value of 33 inch and 42 inch car wheels upon long-distance express trains, the Boston and Albany Railway is preparing to place the larger size under all its New York through passenger cars. The life of the usual

cast iron 33 inch wheel on these long running trains is about four years, but of late the steel-tired wheel has been run a very much longer time. The new wheels will be of the steel-tire pattern, and made by a Hartford, Conn., company, and the change in all its incidentals will involve an outlay of over £5000. The superintendent expects to secure not only a stronger wheel but one less liable to catch at the joints and pound the rail ends, much less friction in the journals, and less danger from hot boxes.

"To whom are we indebted for the Railway Ticket System," is the title of a small pamphlet, in which Mr. J. B. Edmonson gives an account of the origin, invention, and rise of the railway ticket system, as now adopted by almost every railway company throughout the world. The invention and system are due to the labors of one Thomas Edmonson, who was born in 1792, became connected with railways in 1844, and seeing the disadvantage connected with the paper voucher written and supplied to passengers, contrived a rude method of printing cards, arrangements for numbering them, and cases in which the tickets thus made could be arranged and kept for issue. The printing apparatus was at first very crude, but the arrangement of the ticket cases and tubes are now very much the same as when Edmonson contrived them. He subsequently designed very complete machinery for printing, numbering, and checking the numbers of the tickets, and designed arrangements of color and number for purposes of checking the receipts. The pamphlet is published by H. Blacklock & Co., Manchester.

Some interesting information is conveyed by the recent report of the Board of Trade on the railways of the United Kingdom during 1877. These reports are not usually very attractive reading, but having overcome one's mental inertia, we are enabled to learn from them something that is not the less useful because it is somewhat discomforting. With all our railway improvements, our working expenses grow rather than decrease, though a few lines must be excepted. Thus in 1870 the maintenance of way cost 5.89d. per train mile, in 1877 this was increased by 1.63d., locomotive power cost 1.07d. more, traffic expenses 2.24d., and other items 0.86d. more. The ratio of expenditure to traffic receipts, though rather less than in 1876, was 54.1 per cent. For the last five years the proportions have been: 1873, 54 per cent.; 1874, 55.6 per cent.; 1875, 54.6 per cent.; 1876, 54.2 per cent.; and 1877, 54.1 per cent. In 1870 it was but 48.8 per cent. Now as the difference of a penny per train mile amounts to about a million sterling, and of 1 per cent. in the proportion of expenditure to receipts, to about £600,000, there would be an enormous addition to the net earnings of the companies if they could get back to anything like the working expenses of 1870.

Railways are in course of construction in Russia in Asia. Contractors' trains are now, it is said, running over the Ural Mountains to the city of Ekaterinereburg, just on the Asiatic side. This place is in about latitude 57 and in longitude 60 deg. east of Greenwich, that is, about 100 miles further north and 800 miles further east than Moscow—as far north as Aberdeen and as far east as the head of the Indian Ocean. There is now on the Eastern Continent a continuous line of railroad from longitude 10 west to 60 degrees east of Greenwich, the western terminus being south of latitude 40, and the eastern about latitude 57. This exceeds the extent of the North American system from about 46 west of Greenwich—Halifax—to 105 west—San Francisco. The European system covers 70, the North American 59 degrees of longitude. The railroad enters Ekaterinereburg from Perm, which is about 190 miles north-west, by a high level line, and in that inland and elevated district must have a very severe winter. It is not quite so far north as St. Petersburg and the Finland railroads, but the latter have the winters somewhat modified by the nearness of the Baltic Sea; while Perm has no sea nearer than 800 miles, and that is the arctic, and the Ural range is close by. The road from Perm to Ekaterinereburg, 310 miles, was to be opened to the public September 1st, and a good deal of work has been done on an extension of the road into Siberia.

The final result of English railway working in 1877 may be stated as follows: The extent of the system increased 1.2 per cent., the double mileage 0.7 per cent. The capital increased 2.4 per cent., and the capital per mile open increased 1.2 per cent. The ordinary capital increased more slowly than the total capital, or only 1.2 per cent. The gross receipts increased 1.2 per cent., or rather less than the rate of increase of capital; but the working expenditure increased only 1.0 per cent. so that the increase of net earnings is 1.5 per cent. The receipts, expenditure, and net earnings per train mile have all decreased slightly. The result is (1) a slight diminution of the percentage of net earnings on the whole capital, viz., from 4.36 to 4.32 per cent., and (2) a slight diminution of the dividend paid on the ordinary capital, viz., from 4.52 to 4.51 per cent. These are the results in a year in which the increase of traffic was at a lower rate than at any time since 1858, the average rate having been in that period 4.65 per cent., while last year it was only 1.21 per cent. They are also the results at a time when the rate of working expenses is at a high level compared with the whole period prior to 1872. The result to railway capitalists cannot be deemed unfavorable, though the average is composed in part of some unfavorable extremes. As regards the public use of railways, the increase of third-class traffic, as well as of minerals and goods conveyed, would appear to show that that use has been increased in 1877 in a greater degree than the return to the owners of the railway system.—*Engineer.*

The use of chilled cast iron wheels is, according to a correspondent of the *American Railroad Gazette*, slowly but steadily getting into favor in Europe, especially on the Austro-Hungarian railroads, which have for many years been using them with the best results. In the year 1844, Mr. A. Ganz, a Swiss citizen, established in Buda a foundry; and in 1854,

being induced by some railroad engineers, he began to experiment in chilling cast iron; and, having on hand Hungarian ores of superior quality, he was able, in 1857, to execute some important orders for chilled wheels for the Austrian and Hungarian railroads. The highest number of wheels produced by this establishment in a year was 36,000, in the year 1872; but owing to the industrial crisis of 1873 it has fallen off, and only during the last two years has been increasing again, amounting now to 22,000 wheels a year. In 1867, 100,000 had been cast, 200,000 in 1871, 300,000 in 1874, and 400,000 will probably have been cast by the beginning of next year. The wheels were furnished to thirty different railroad companies. The manufacture of railway crossings from the material is also an increasing industry. The depth of the chill of the wheel tread is from $\frac{3}{8}$ inch to nearly $\frac{5}{8}$ inch. Specimens of wheel sections are exhibited in the Paris Exhibition, and some old wheels, among which, one No. 423, has run 128,987½ miles, and another, No. 3684, has run 340,446$\frac{5}{10}$ miles, as certified to by the Mohacs-Fünfkirchen Railroad Company. They are both from under cars in light service, and hardly show any wear. Baron M. M. von Weber, in his report to the Government (Vienna, May 31, 1874), recommended chilled wheels for luggage trucks, as being more economical and safe; he states that there is but one-tenth as many accidents from the breaking of chilled wheels as from others.

THE long talked of project of a railway across the island of Newfoundland has been revived by an Act of the Legislative Assembly proposing to grant an annual subsidy of £24,000 to any company which shall construct and maintain a railway across the island, in addition to granting liberal concessions of Crown lands. The argument is that such a road would not only open up immense deposits of copper, iron, coal, nickel, lead and other minerals, great pine and spruce forests, and vast tracts of rich land, capable of producing in abundance the finest quality of wheat, but would virtually bring America almost a thousand miles nearer Europe by making practicable the establishment of a line of steamers from St. John's, a point nearer to Great Britain than New York by almost that distance, while also avoiding the dangerous part of the voyage between New York and Cape Race. That a railway across Newfoundland would develope a large traffic is, says the *Railway Age*, unquestionable; that it would result in a considerable diversion of ocean travel from New York to St. John's is somewhat doubtful.

ENGINEERING STRUCTURES.

COST OF MAINTENANCE OF HIGHWAYS IN AND AROUND PARIS.—From a late number of Annales des Ponts et Chaussees we make the following abstract of the report of M. Graeff, Inspector General of Bridges and Roads.

The government appropriation for this department for 1878 having been fixed at three million francs, M. Graeff calls attention to the fact that as the total estimate called for 7,578,471 francs there would remain a requisition upon the city for upwards of four and a half millions if the projected plans were executed.

The estimates of cost of this and former years show a gradual increase of cost of repairing each of the three kinds of road surface now in use: viz., pavement, asphalt and broken stone.

The cost of maintaining paving was from 1872 to 1875, 0f.48 per square meter, in 1876 it was 0f.51 and the estimate for 1878 is 0f.53.

For asphalt the cost from 1872 to 1875 was 1.f20 in 1876 1.f30 and estimated for 1878 at 1.f27 per square meter.

For broken stone (macadamized) roads from 1872 to 1875 the cost was 1f.80 in 1876 it was 2f.11 and is estimated for 1878 at 2 francs per square meter.

These figures show an advance in cost over previous years, except for the year 1876 in which the prices for asphalt and broken stone were slightly above the current estimates. It appears that the advanced prices are due to increased expense of both materials and labor.

The above estimates lead to the suggestion that pavement be substituted for the macadamized surfaces except in streets used mainly by pleasure carriages, but it is added it does not seem practicable to restrict the use of broken stone any further at present. Economy in this direction is only to be accomplished by securing the most durable road material.

In the meantime many of the streets need repairing. They are in general only in fair condition, and some are actually bad. It is estimated that keep the thoroughfares in normal condition $\frac{1}{12}$ of their total surface should be renewed, and it is to be regretted that the appropriation for the current year will allow a renewal of only $\frac{1}{17}$ of their entire surface.

WIRE ROPE CONVEYANCE.—By M. Korting.—A system of aerial transit on suspended wire ropes, designed by Messrs. Bleichert and Otto, of Leipzig, has been established to connect the gasworks at Hanover with the neighboring coal station on the Hanover-Altenbeck railway, for the supply of coal to the works. The line crosses the Limmerstrasse and the river Ihme, and is about 625 yards in length. There are two iron-wire ropes, placed 5 feet 10 inches apart, and employed respectively for the carriage of loaded and of empty wagons. They cross the Limmerstrasse at a height of 23½ feet, and the river at about 30 feet. The cables are respectively 1.12 inch and 1 inch in diameter, and are constructed of wire of 4 millimeters, about ⅛ inch, in diameter. They are supported on pulleys at intervals of 24 yards, except in crossing the river, on a span of 57 yards. Resting on pulleys, they are free to expand or contract. They are kept taut by weights of 5 tons and 4 tons respectively.

The wagons are drawn by means of a $\frac{9}{16}$ inch endless wire rope, supported on rollers at intervals of 60 yards, and driven by a six-horse steam engine at a speed of three miles per hour. The wagons are constructed of sheet-

iron, and are capable of holding three hectoliters, or 106 cubic feet of coal; they are suspended from the carrying ropes on two grooved wheels, one in advance of the other, between which the attachment of the wagon is made. The bodies of the wagons are swivelled, so that they may be easily emptied. They follow each other at intervals of about 60 yards. Allowing for delays, the quantity of coal carried at no time exceeds 180 tons per day of ten hours, and is frequently less, the average delivery being only 135 tons. The working charges are:

	£.	s.	d.
Seventeen men at 2s. 6d.....	2	2	6
One carpenter.....	0	3	5
Coal for the engine.....	0	6	4
Oil, waste, &c.....	0	0	5
Per day.....	£2	12	8

being at the rate of 4.67*d.* per ton of coal conveyed. The total first cost of the system amounted to £3,580, and the charge for interest, depreciation, and 15 per cent. for maintenance, is reckoned at 5.13*d.* per ton, making a total charge of 9.8*d.* per ton, the former cost being 1*s.* per ton.

MACADAMIZED ROADS.—Attention is being directed to the condition and mode of construction of macadamized roads in London. It is stated, and there seems reason for the statement, that the streets paved in this way deteriorate much more rapidly since the date of the adoption of the steam road roller than they did formerly. The reason for this is sought in the difference in the size of the pieces of stone now used and those used by M'Adam. M'Adam employed road material consisting of pieces not larger than would pass through a ring under 2 inches in diameter, but a large proportion of those now used are not less than double the weight of the pieces so measured. The stone was formerly broken by hand, but machinery does the work, so that the cost of breaking should not be the explanation of the increase in size, more especially as sand and gravel is now employed during the rolling of the newly laid metal for binding it together. This binding, it is argued, is only required in consequence of the increased size of metalling, and that is soon washed away, leaving the large stones loosened and easily removable. Hence it is said that the roads are soon now in holes because the metalling is too large. On the other hand it is argued that, as the roads are now pressed by the heavy steam roller in place of the wheels of ordinary vehicles and comparatively light rollers, larger stones are admissible. It, however, remains to be learned by roadmaking engineers who have the opportunity of observation, whether the roadway is really as solid after the steam roller, as is usually imagined, or whether the circular rollers do not leave it in a condition somewhat loose at least near the surface. It has also to be learned whether the alteration in the size of the metalling is attended with inferior results and whether breaking the stone so small originally is not simply helping the ultimate disintegration. It has also to be proved that the increase in the traffic is not the main cause of the increased wear of the roads. That the more rapid wear has noticeably taken place since the adoption of the steam rollers does not offer any argument against the use of the latter, inasmuch as the increase of traffic in the same time has in more districts been remarkable. There is reason, however, for believing that the use of more finely broken road metalling would, especially if mixed with a small quantity of, say, Northamptonshire blast furnace slag broken to a small size, when well rolled and compacted under the steam road roller, make a more durable road than is now made with large metalling and gravelly sand.

ORDNANCE AND NAVAL.

TELESCOPIC ARTILLERY SIGHTS.—We understand that the French Government, being satisfied with the preliminary trials with the telescopic sights invented by Captain Scott, R.E., have purchased three instruments to enable them to carry out exhaustive trials. The object of his invention is:—(1) To enable the gunner to take aim at distances equal to the full range of the gun. (2) To dispense with the errors of fire due to the inclination of sights when the gun wheels are out of level. (3) To enable the gunner to correct errors in range and direction by infallible mechanical adjustments, instead of calculations based upon guesswork—good or bad according to the experience of the firer.

THE EXPENDITURE OF AMMUNITION.—The *Russian Invalide* adds some facts to those published in the Moscow *Gazette*, concerning the expenditure of ammunition by the Russians. According to this account the Russian artillery used 204,923 charges, and the infantry and cavalry 10,057,764 cartridges, which are distributed as follows:—Field Artillery—1288 guns, 114,879 shells, 43,029 shrapnels, 1091 cases of grape shot; together, 158,999 charges, or 123.46 per gun. Siege Artillery—151 guns, 23,995 shells, 24,095 bombs, 4174 cases of grape shot; together, 52,264 charges, or 346.12 per gun. Small arms—65,000 Berdan rifles; 3,625,364 cartridges, or 45.75 each; 37,000 cavalry carbines; 1,251,764 or 33.72 each; 217,000 Kruka rifles, 5,692,120 or 26.22 each; 16,000 revolvers, 88,516 cartridges or 5.42 each; together, 335,000 small-arms of all descriptions, which discharged 10,057,764 cartridges, or 30 each. According to the *Russian Invalide*, the number of troops engaged in actual fighting was 282,000 infantry, 37,000 cavalry, or 319,000 men, with 1288 field guns, making 3.9 guns to 1000 men. The large number of cartridges, viz., 1,251,764 from 37,000 rifles, expended by the cavalry, demonstrates the important part played by the cavalry during marches, and in its employment as infantry on fields of battle. The Turks are reported to have lost, in Europe and Asia, nearly 150,000 dead or wounded, which would indicate that about sixty-seven cartridges were required to place one man *hors de combat*, taking no account of artillery. The proportion of rifle firing to artillery fire is as 49 to 1.

PALLISER ON PROJECTILES.—Sir W. Palliser has written a letter, suggested by the artillery experiments which have recently been carried out, in which he says that they uphold, to the satisfaction of all, the principles advocated by him during the last fifteen years in connection with iron plate penetration. These are:—(1) That the form of the projectile should be such that the pressure of the plate should be brought to bear gradually on the projectile: and (2), that the projectile should be composed of a substance which offers a great resistance to pressure. These principles sound childlike in their simplicity; still they were opposed to the received opinions of the day. In advocacy of the principles the writer says: "I applied them by making a pointed (technically an ogival-headed) projectile of common cast iron of a hard nature, which is further hardened and compressed by casting in a peculiar mold. The results of my invention were so great that the Government of the day ordered that these projectiles should be officially designated the 'Palliser Projectiles.' All that now remains to me of them is their name. I trust the writer of your article does not wish to rob me of that too, for he makes no allusion to it in connection with them. If by any process it were possible to impart to ogival-headed projectiles of steel, or of silver, or of gold, the same property of resisting pressure imparted to the cast iron in my projectiles, then a Palliser projectile of steel, silver, or gold would be produced which would, no doubt, give as good results as those of cast iron. Experience has shown that it is very difficult to impart this property with any certainty into steel in large masses, and that its existence cannot be proved excepting by trial in the same manner as the Austrian soldier-servant tried his master's lucifer matches and found them all good, to the officer's great disgust when he wished to light his candle in the night. It is possible that similar difficulties might be met with in the construction of silver or gold projectiles. But why should public money be wasted in this way when thoroughly reliable projectiles can be produced from cheap cast iron which do all that can be required of them—viz., which will penetrate as far as the gun has power to drive them? Moreover, these projectiles possess the valuable quality of separating themselves into many pieces in planes, as a rule parallel with, and at right angles to, the axis of the projectile." Notwithstanding the progress in artillery since these principles were first enunciated by Sir W. Palliser, he believes firmly in the superiority of his projectiles for penetrating iron plates, and holds that, provided his first principles be true, nothing will ever be produced to surpass them.

BOOK NOTICES.

A DESCRIPTIVE TREATISE OF MATHEMATICAL DRAWING INSTRUMENTS. Fifth Edition. By Wm. FORD STANLEY. New York: E & F. N. Spon. Price $2.00. For sale by D. Van Nostrand.

A full description of all the implements employed by the draughtsman is certainly a useful book. Four editions of the book are in the hands of students in different parts of the world.

HISTOIRE NATIONALE DE LA MARINE. Par JULES TROUSSET. Paris: Libraire, M. Dreyfous. Price $4.00. For sale by D. Van Nostrand.

This voluminous history of the navies of Europe is quite fully illustrated with portraits and naval battle scenes. The pictures are of medium quality only. The typography is good enough and there is a good deal of it—nearly 800 pages of large royal octavo size.

HANDBOOK OF MODERN CHEMISTRY, ORGANIC AND INORGANIC. By Dr. MEYMOTT TIDY. London: J. & A. Churchill. Price $5.00. For sale by D Van Nostrand.

This large work is divided into three parts: non-metallic elements, metallic elements, and organic bodies.

It may be regarded as a compend of chemical reactions and of the resulting compounds. It is not a book for a student, but will prove of good service to the working chemist or to the instructor.

It is well printed, contains 776 pages of matter, but no illustrations.

EXPERIMENTAL RESEARCHES IN PURE, APPLIED AND PHYSICAL CHEMISTRY. By E. FRANKLAND, D.C.L.; F.R.S. London: John Van Voorst. For sale by D. Van Nostrand. Price $15.00.

The eminence of the author will insure a cordial reception for this work. A portion of this volume has already found a place in standard scientific works, having been published in the chemical journals in separate memoirs during the past thirty years.

This book of 1030 pages presents the record of this author's labors down to the present time.

The typography, especially of the chemical formulas, is excellent.

THE ARTISAN. By ROBERT RIDDELL. Philadelphia: Claxton, Remsen & Haffelfinger. Price $5.00.

This is in an instruction book for the use of students. It is mainly a set of illustrative examples beginning with practical geometrical problems and leading up to designs for timber constructions of various kinds. There are forty full page plates of quarto size, and a page of text facing each plate.

Among other examples of a practical kind we find: Finding bevel cuts for splayed work; Butt-joints for acute Angles; Construction of High-Roofs; Construction of Niches; Platform Stairs; Hand-Railing, ets., etc.

The typography and plates are exceedingly good.

PROCEEDINGS OF THE INSTITUTION OF CIVIL ENGINEERS. Excerpt Minutes. Edited by JAMES FORREST, A.I.C.E., Secretary.

We have received through the kindness of Mr. Forrest the following papers of the Institution:

The Construction of Steam Boilers, adapted for very High Pressures, by James Fortescue Flannery.

Portland Cement Concrete, by John Watt Sandeman, M.I.C.E.

Portland Cement Concrete in Arches and Portland Cement Mortar, by Charles Colson, A.J.C.E.

A Skeleton Pontoon Bridge, by Bagot William Blood, M.J.C.E.

ANNUAL REPORT UPON THE SURVEY OF THE NORTHERN AND NORTHWESTERN LAKES, AND THE MISSISSIPPI RIVER. In charge of Gen'l C. B. COMSTOCK. Washington: Gov't Printing Office.

This is an Appendix to the Report of the Chief of Engineers for 1877. It contains four folding plates representing the systems of triangles about the great lakes, also four plates exhibiting by curves the changes of water level in the lakes separately.

Some detailed accounts of the measurements of a base line and of astronomical work will be especially interesting and instructive to students of geodetic surveying.

THE PHYSICAL SYSTEM OF THE UNIVERSE—AN OUTLINE OF PHYSIOGRAPHY. By SYDNEY B. J. SKERTCHLY, F.G.S. London: Daldy, Isbister & Co. For sale by D. Van Nostrand. Price $3.00.

The writer sums up in a careful way the evidence bearing upon the theories of Geology and Physical Geography.

The topics taken in order are, as presented by the author in chapters, are: I, Introduction; II, Matter and Motion; III, Light; IV, The Sidereal System; V, VI, and VII, The Solar System; VIII, The Sun; IX, X, The Earth's Internal Heat; XI, and XII, The Earth's External Heat; XIII. Climate; XIV, Life; XV, The Nebular Hypothesis.

EXAMPLES OF MODERN STEAM, AIR AND GAS ENGINES. By JOHN BOURNE, C.E. London: Longmans, Green & Dyer. For sale by D. Van Nostrand. Price $30.00.

This work was begun some few years since and issued in parts, each part being a quarto with generally a folding plate and several large wood cuts interspersed in the text. After a long interruption to the publication, the final parts have appeared, and the work as completed is a large quarto with fifty plates and about 400 wood cuts.

The illustrations are so complete as to details that the explanatory text is scarcely necessary. The plates are in most cases "working drawings," and all moderm improvements are discussed.

DICTIONNAIRE DE CHIMIE. PURE ET APPLIQUEE. Par AD. WURTZ. Paris: Libraire Hachette et Cie. For sale by D. Van Nostrand.

This Dictionary is now complete. It includes Organic and Inorganic Chemistry; their applications to manufactures, agriculture, and the arts; also their bearing upon Physics, Mineralogy and upon Physical and Chemical research.

No pains have been spared to present topics with a proper degree of fullness and pictorial illustration.

References to the sources from whence the articles have been condensed are given with satisfactory completeness.

In these days of rapid advance in Applied Chemistry, such a compend of Chemical Processes is to the Analyst or Manufacturing Chemist indispensable.

REPORT ON BRIDGING OF THE RIVER MISSISSIPPI BETWEEN SAINT PAUL, MINN., AND ST. LOUIS, MO.—By Brevet Major General G. K. WARREN,—Major of Engineers. 232 pp. 8vo., with many maps. Washington, 1878. For sale by D. Van Nostrand.

The report on bridging the Mississippi River between St. Paul, Minn., and St. Louis Mo., by Gen. G. K. Warren, is a very valuable contribution upon the subject of bridging navigable waters. Ordinarily, bridges have been constructed for highways and railroads, only in the interest of the companies building them, and with little or no attention to the interests of navigation. In all cases where there has been a considerable amount of water traffic, it is true that the companies have been compelled to build draws, but these have often been very badly situated and of difficult and dangerous passing, and it was only when the navigation interests of a great public highway like the Mississippi became involved that sufficient influence was brought to bear upon the question to protect the navigation from unnecessary obstruction by the bridges that must inevitably be built. The matter was brought before Congress, and General Warren was appointed to make the necessary examinations, and report. The interests involved in the construction of railway bridges over the Mississippi and other large navigable channels are diametrically in opposition. On the one side, the railway companies desire to build bridges on the grade of their road, in the best line for them across the stream, and wish the most economical spans; and almost invariably prefer a low structure with a draw, rather than construct a high bridge under which steamboats can pass. On the other side, the river traffic demands bridges at right angles to the current, with piers in its exact direction, wide spans, and a superstructure which any boat navigating the river can pass under at high water. It was chiefly with a view to determine how these conflicting interests could be reconciled, that the investigations conducted by General Warren were ordered by Congress. The duty assigned to him has been admirably performed. He appears to have impartially considered the rights of all parties, and to have brought a vast amount of keen observation and practical good sense to bear upon the questions involved. He appears to have considered the subject in all its engineering, commercial, financial and legal bearings, and to have collected data and documents to support his deductions, so that any one reading his report can see the reasons upon which he bases his conclusions.

Gen. Warren commences by stating the origin and nature of the investigation, and gives a general description of the Mississippi valley in connection with that of the Minnesota river. He considers the geographical structure of the

region embraced by the report, and advances the hypothesis, previously more fully set forth in his report upon the Minnesota River (Report of Chief of Engineers, 1875) that the water from Lake Winnipeg once flowed southward into the Mississippi through the Minnesota valley. There seems from his statements no good reason to doubt the correctness of his theory. He next gives a general presentation of the requirements and advantages of western river navigation, the necessity for wide spans and high bridges, and a discussion of the data for determining the headway required. He then gives a description, with maps and diagrams showing the location and character of the several bridges that have been constructed between St. Louis and St. Paul; likewise showing the direction of the river current through the openings between the piers. A comparison of these in the different bridges is very interesting. One of the bridges described, the new bridge at Rockland, was designed and located, as well as partially constructed under his immediate direction. He then goes on to give a general history of bridging the navigable western rivers, in its relations to the laws, to the decisions of the United States Courts, and the debates in Congress. He also gives the opinions of many eminent engineers with relation to the length of spans practicable and other points of interest. He concludes with an acccount of the manner in which his examinations have been made. The whole report shows the utmost attention to facts and details of value for future reference, and represents the immense amount of work performed by General Warren and his assistants.

As an engineering essay upon the location and general character of bridges over large navigable streams it is of great value to the profession, both on account of the numerous examples given with their advantages and defects, and the plain statement of the principles involved and which are as applicable to other streams as to those described.

GRAPHICAL STATICS. By A. JAY DUBOIS. (A communication from the author.)

DEAR SIR:—I notice in the November No. of the MAGAZINE a criticism upon the first edition of my "Graphical Statics," translated from the *Zeitschrift des Ver. Deutsch, Ing.* The extract is but a partial one, and it seems, to me, at least, somewhat unjust that the few surly and grudging words of commendation which the author of the critique felt obliged to give me for a work of great labor, evidently much against his will, should have been entirely omitted by your translator, and only his animadversion given to the public.

With an honestly written and intended criticism, whether complimentary or the reverse, I have not, however, and never shall have, fault to find, and certainly shall not take it upon me to answer. The same holds good for the malicious attacks of personal hostility. Witness: A criticism which appeared in your own columns in February of this year, the tone and tenor of which were so personal and malicious that it was beneath contempt, and formed its own best reply. Small wonder that it went begging acceptance of respectable journals until it finally found a lodgment in your columns. If my work is not its own best defense from such palpable attacks, little that I could say, even were I willing to say it, would have any effect.

When, however, a specific charge of dishonesty is made, I consider it my duty to meet it squarely and brand it as slander.

The charge is as follows: "The American reader is led to infer from DuBois' method of reference that only one page of his Introduction is taken from Weyrauch; when, in fact, as I find after a thorough examination, there are twenty-seven pages of close translation." This I brand as a slander, and I wish to call public attention to its entire lack of foundation, and the source from whence it emanates. I will do its author the justice to suppose that it is unintentional and due more to ignorance of the English language, or, perhaps, to natural stupidity, rather than to real malevolence. If not malevolent, however, it is certainly very stupid and very conceited. If, instead of the words "American reader," the critic had spoken for himself alone, he would at least not have been guilty of the conceit of supposing the American reader as stupid as himself.

It is, at best, a very stupid error, and considering the gravity of the charge, an unpardonable one. No acknowledgment could possibly be fuller than that which I have made. I state in the Preface that I am indebted for the Introduction, with few alterations, to Prof. Weyrauch, and I give the full title of the brochure translated. That the astute critic cannot find any alterations does not prove their non-existence, but rather illustrates still more forcibly his cast iron "*dumbness.*" Not content with this acknowledgment in the Preface, which certainly covers the Introduction sufficiently, I have, upon the first page of the Introduction, refreshed the memory of the reader by a foot-note again referring to the original. This is the "method of reference" which misleads, according to our wiseacre, American readers!

Again, the "first page," which seems to bother him so, closes as follows: "We have, therefore, to ask of the reader who wishes to obtain a just and accurate estimate of this new, and, as we venture to think, highly important subject, patience for the following general consideration." Then follows in succeeding pages these considerations. It has remained for our sagacious German critic to make the discovery that all this acknowledgment refers only to the "first page," in spite of the context as given above!

It is much to his credit that no one else has ever been accurate enough to make this astonishing discovery, not even the "American reader," who will even find difficulty in seeing it when pointed out. As to Prof. Weyrauch, who ought certainly to be the best judge of what is due himself—he has expressed himself as highly pleased and gratified. But then he is not an "American reader," or rather, he is a much better one than our critic. My intimacy with him justifies me in the promise that he will himself answer in my behalf, over his own

name, this accusation in the JOURNAL, where it originated, when, *of course*, you, Mr. Editor, will be only too delighted to translate it also for the benefit of the much enduring "American reader."

When I add that Prof. Weyrauch's little pamphlet is of popular interest, that it was received by me while the book itself was in press and inserted by way of a popular introduction, and that it is entirely separate and apart from the body of the work, with which it has nothing whatever to do, I am sure this same "American reader" will be lost in admiration at the amiable temper of our critic, and will wonder at the acuteness which discovered so much—which has no connection whatever with the book proper, to growl about.

I have stated in my Preface, and wish to repeat here, once for all, that I have indicated fully all obligations, and have been glad to do so, as much for my own credit as for the advantage of the student. Such references are not as frequent in many works of higher pretensions as they might or ought to be. I have yet to learn of any dissatisfaction with my "method of reference" from those concerned. On the contrary, the kind expressions I have received are a sufficient answer to any such imaginary charges from incompetent sources. The critic's incompetency peeps out in many places. For instance, he insinuates doubt as to the thoroughness of my study of "Favaro and others." Considering that Favaro appeared later and has studied and acknowledged indebtedness to me, I am inclined to the same suspicion as regards our German friend.

The sum total is, that, with considerable labor and a pretty fair knowledge of my subject, I have produced a work which, whatever its demerits, can at least lay claim to honest intention and execution, and which is not devoid of original merit. I would, therefore, state, once for all, that any imputations upon my honesty must not be based upon my work, or it will be at the risk of the accuser, and may possibly end in putting him in an unenviable situation as regards his own honesty of purpose.

A. J. DU BOIS.

MISCELLANEOUS.

THE POPULATION OF THE EARTH.—The fifth publication of Behm and Wagner's well-known "Bevolkerung der Erde," is just out, giving some elaborate statistics on this subject.

Since the last publication of these statistics the population of the earth shows a total increase of 15 millions, partly arising from natural growth and partly the outcome of new and more exact censuses. The total population is now set down at 1,439,145,300, divided among the Continents as follows:—Europe, 312,398,480; Asia, 831 millions; Africa, 205,219,500; Australia and Polynesia, 4,411,300; America, 88,116,000. The following table gives the latest results for the chief countries in the world:—

EUROPE.	
Germany, 1875	42,727,360
Austria-Hungary, 1876	37,350,000
Liechtenstein, 1876	8,664
Switzerland, 1876	2,759,854
Netherlands, 1876	3,865,456
Luxembourg, 1875	205,158
European Russia, 1872	72,392,770
Finland, 1875	1,912,647
Sweden, 1876	4,429,713
Norway, 1875	1,807,555
Denmark, 1876	1,903,000
Belgium, 1876	5,336,185
France, 1876	36,905,788
Great Britain, 1878	34,242,966
Faroes, 1876	10,600
Iceland, 1876	71,300
Spain (without Canaries), 1871	16,526,511
Andorra	12,000
Gibraltar, 1873	25,143
Portugal (with Azores), 1875	4,319,284
Italy, 1876	27,769,475
European Turkey (before division)	9,573,000
Roumania, 1873	5,073,000
Servia, 1876	1,366,923
Montenegro	185,000
Greece, 1870	1,457,894
Malta, 1873	145,604
ASIA.	
Siberia, 1873	3,440,362
Russian Central Asia	4,505,876
Turcoman Region	175,000
Khiva	700,000
Bokhara	2,030,000
Karategin	100,000
Caucasia, 1876	5,391,744
Asiatic Turkey	17,880,000
Samos, 1877	35,878
Arabia (independent)	3,700,000
Aden, 1872	22,707
Persia	6,000,000
Afghanistan	4,000,000
Kafiristan	300,000
Beloochistan	350,000
China proper	405,000,000
Chinese border lands, including Eastern Turkestan & Djungaria	29,580,000
Hongkong, 1876	139,144
Macao, 1871	71,834
Japan, 1874	33,623,373
British India within British Burmah, 1872	188,421,264
Native States	48,110,200
Himalaya States	3,300,000
French Settlements, 1875	271,460
Portuguese do. do	444,617
Ceylon, 1875	2,459,542
Laccadives and Maldives	156,800
British Burmah, 1871	2,747,148
Manipur	126,000
Burmah	4,000,000
Siam	5,750,000
Annam	21,000,000
French Cochin China, 1875	1,600,000
Cambodia	890,000
Malacca (independent)	290,000
Straits Settlements	308,097
East Indian Islands	34,051,900
AUSTRALIA, &C.	
New South Wales, 1876	630,843
Victoria, 1876	841,938
South Australia, 1876	229,630
Queensland, 1876	187,100
West Australia, 1876	27,321
Tasmania, 1876	105,484
New Zealand and Chatham, 1876	444,545
Rest of Polynesia	1,896,090